Miscellaneous Paper W-95-1
February 1995

**US Army Corps of Engineers**
Waterways Experiment Station

*Dredging Operations Technical Support Program*
*Water Operations Technical Support Program*

# Water Quality '94 Proceedings of the 10th Seminar

## 15-18 February 1994
## Savannah, Georgia



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Prepared for Headquarters, U.S. Army Corps of Engineers

Dredging Operations Technical Support Program
Water Operations Technical Support Program

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Final report



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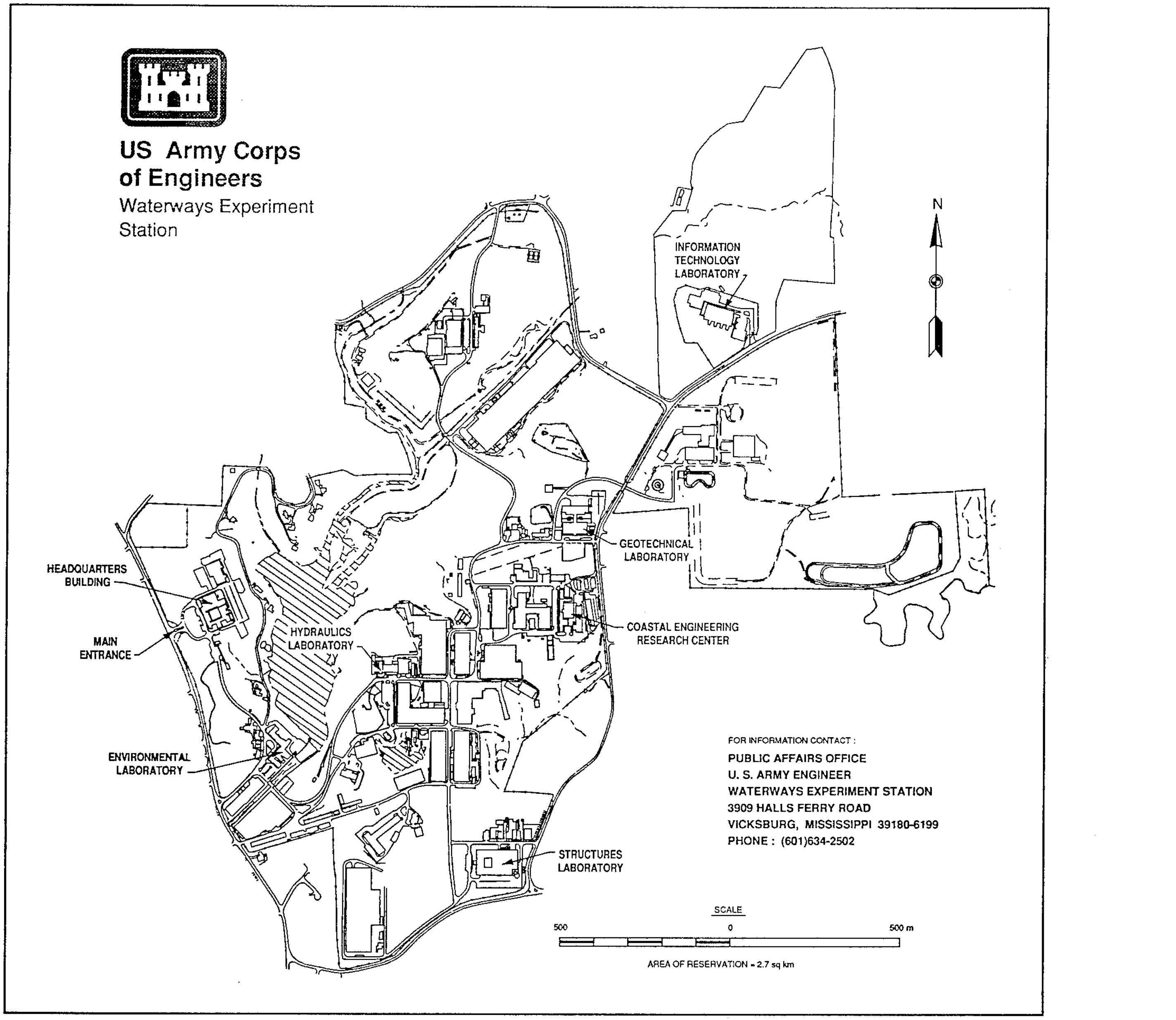


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# Contents

# Preface

The U.S. Army Corps of Engineers 10th Seminar on Water Quality was held in Savannah, Georgia, on 15-18 February 1994. The seminar was co-sponsored by the Committee on Water Quality (CWQ), the U.S. Army Engineer Waterways Experiment Station (WES), and the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers Water Resources Support Center.

The organizational activities were carried out under the general supervision of Dr. Robert M. Engler, Program Manager, Environmental Effects of Dredging Programs (EEDP), Environmental Laboratory (EL), WES. Mr. Thomas R. Patin, Program Manager, Dredging Operations Technical Support (DOTS) Program, was responsible for planning the meeting. Dr. John W. Keeley was Director, EL, WES. Mr. Frederick B. Juhle was Chairman, CWQ, for the Headquarters, U.S. Army Corps of Engineers.

The seminar agenda was prepared by Messrs. Patin and Robert C. Gunkel, WES. Mr. Patin was responsible for coordinating the necessary activities leading to publication.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

# Agenda

## *Tuesday, 15 February*

### Plenary Session

(Chairman - Frederick B. (Pete) Juhle, HQUSACE)

0800-0815 **Welcome**
Robert Engler, WES

0815-0830 **Remarks of Chairman, Committee on Water Quality**
Pete Juhle, HQUSACE

0830-0900 **HQUSACE Overview**
Earl Eiker, HQUSACE

0900-0930 **Concepts of Risk Assessment, Risk Management**
Tudor Davies, EPA

0930-0940 **WOTS Update**
Bob Gunkel, WES

0940-0950 **DOTS Update**
Tom Patin, WES

0950-1010 **Performance-Based Water Quality Management**
Richard Price, WES

1010-1030 **Break**

### Session 1, Inland and Riverine Issues

Chairman - Dave Brown, SWD

1030-1050 **"Partnering" for Technology Transfer in the Corps**
Harold T. Sansing, ORN

1050-1110 **The Nature of the Beast**
John Anderson, MRO

1110-1130 **High-Speed System for Synoptic Assessment of Riverine Near-Surface Water Quality Conditions and Spill Response**
William Cremeans, ORH

1130-1150 **Effects of the Tioga-Hammond Flood Control Project on Water Quality of Tioga River**
Kenneth Kulp, NAB

1150-1210 **Gas Supersaturation at Jennings Randolph Lake**
Kenneth Lee, NAB

1210-1310 **Lunch**

1310-1330 **Water Quality Changes as a Result of Coldwater Releases in Lake Moomaw**
Mark Hudgins, NAO

1330-1350 **Onondaga Lake Restoration**
Stephen Yaksich, NCB

1350-1410 **Trail Creek/Michigan City Federal Harbor Sedimentation Study**
Rick Sutton, NCC

1410-1430 **Break**

1430-1450 **Quantifying the Effects of Motorized Watercraft on Water and Sediment Quality, Fox Chain O'Lakes, Illinois**
John Yagecic, NCC

1450-1510 **Demonstration of Water Injection Dredging on the Upper Mississippi River**
Teri Sardinas, NCD

1510-1530 **A Riverine Emergency Management Travel Time Model and Its Application to Mississippi River Basin**
R. Pomerleau, NCS

1530-1550 **Finger Lakes Biological Response Study**
Daniel Wilcox, NCS

1550-1610 **Assessing Water Quality Impacts of Columbia River System Operating Strategies**
Bolyvong Tanovan, NPD

1610-1630 **Restoration of Renown Trout and Salmon Fishery: Evaluation of Selective Withdrawal Retrofit, McKenzie River Basin, Oregon**
Russell Davidson, NPP

1630-1650 **Drawdown of Lower Snake River Reservoirs: Sediment Erosion and Resulting Water Column Impacts**
Thomas Miller, NPW

1650-1710 **Smithland Locks and Dam—A Dredging Case Study**
Gordon Lance, ORD

## *Wednesday, 16 February*

### Session 1, Inland and Riverine Issues (Continued)
Chairman - Andy Petallides, NAD

0800-0820 **Caesar Creek Lake Water Quality and Modeling Study**
Joseph Bohannon, ORL

0820-0840 **Metropolitan Nashville Regional Environmental Engineering Study**
Tim Higgs, ORN

0840-0900 **Reservoir Tailwater Fisheries of the Upper Ohio River Basin Drainage Basin**
Michael Koryak, ORP

0900-0920 **Water Quality Issues in the Central and Southern Florida Project**
James Vearil, SAJ

0920-0940 **A State and Federal Partnership for Water Quality Investigations for Two Southeastern River Basins**
Thomas Craven, SAM

0940-1000 **Corps Role in Nutrient Reduction to Everglades National Park**
James McAdams, SAJ

1000-1020 **Break**

1020-1040 **Richard B. Russell Lake and Dam Project: Oxygen Injection System**
J. R. Peavy, SAS

1040-1100 **Hydropower and Pump Storage Operation Impacts on Tailwater Thermal Patterns at Richard B. Russell Dam**
Joe Carroll, WES, Calhoun Falls

1100-1120 **Evaluation of Dredging and Dredged Material Disposal Options for Restoration of Hamlet City Lake, North Carolina**
Phillip Payonk, SAW

1120-1140 **Dissolved Oxygen in Releases from White River Basin Lakes**
Gordon Bartelt, SWL

1140-1200 **Overview of the Beaver Lake, Arkansas, Water Quality Enhancement Project**
George Losak, SWL

1200-1300 **Lunch**

### Session 1, Inland and Riverine Issues (Continued)
Chairman - Warren Mellema, MRD

1300-1320 **Brine Disposal Lakes of Southwestern Oklahoma and North-Central Texas; Potential for Selenium-Related Impacts on Wildlife**
Stephen Nolen, SWT

1320-1340 **Special Reservoir Operations for Preserving Famous Salmon Fishery in Rogue River During 1992 Drought, Lost Creek Lake, Oregon**
Mike Schneider, WES

1340-1400 **Evaluation of Impact of Pesticide Runoff on a Delta Watershed Using HSPF**
Carlos Ruiz, WES

1400-1420 **Break**

1420-1440 **Combining a Mechanistic Water Quality Model with Statistical Techniques to Predict Temperature Patterns Downstream of a Peaking Hydropower Dam**
John Nestler, WES

1440-1500 **Bluestone Water Quality Model Study**
Dottie Tillman, WES

1500-1520 **Scope of Corps Involvement in ORSANCO**
Joseph Svirbely, ORD

1520-1540 **Use of the Tiered Testing Approach in Water Quality Evaluations**
David Johnson, LMK

## Session 2, Coastal and Estuarine Issues

Chairman - Gary Mauldin, SAD

1600-1620 **Lake Washington Ship Canal Saltwater Intrusion Control**
Glenn Singleton, NPS

1620-1640 **Assessment of Water Quality Impacts to Lake Pontchartrain, Louisiana, by the Bonnet Carre Freshwater Diversion Project**
Marvin Drake, LMN

1640-1700 **Water Quality and Water Control Issues for the Caernarvon Freshwater Diversion Project**
Burnell Thibodeaux, LMN

1700-1720 **Nitrogen Versus Phosphorus Enrichment of Brackish Waters: Response of Submersed Plant *Potamogeton perfoliatus* and Its Associated Algal Community**
Janet Neundorfer, NAB

1720-1740 **Atlantic Salmon Restoration in New England**
Townsend Barker, NED

## *Thursday, 17 February*

## Session 2, Coastal and Estuarine Issues (Continued)

0800-0820 **Water Releases form Jim Woodruff Dam and the Threatened Gulf of Mexico Sturgeon**
John Zediak, SAM

0820-0840 **Savannah Harbor Navigation Project: Water Quality Changes Following Harbor Modifications**
Diane Hampton, SAS

0840-0900 **Lower Savannah River Environmental Restoration Study**
Monica Simmon Dodd, SAS

0900-0920 **Galveston Bay Model Verification and Salinity Results**
R. C. Berger, WES

0920-0940 **Thirty-Year Simulation of Chesapeake Bay Eutrophication**
Carl Cerco, WES

0940-1000 **When Is a Sediment Bioassay Sufficiently Developed?**
David Moore, WES

1000-1040 **Break**

1040-1100 **Water Quality Problems Encountered on the Appomattox River During a Maintenance Dredging Operation**
Gordon Chancey, NAO

1100-1120 **Water Quality Aspects of Thin-Layer Disposal of Dredged Material**
Pace Wilber, SAM

1120-1140 **San Francisco Bay Dredged Material Disposal Management—The Saga Continues**
T. K., Wakeman, SPN

1140-1200 **Long-Term Management Strategy for Savannah Harbor**
Susan Durden, SAS

1200-1320 **Lunch**

## Session 3, Hazardous Waste Issues

Chairman - Jim Farrell, LMVD

1320-1340 **Hazardous, Toxic, and Radioactive Waste Initial Assessment for Inner Harbor Navigation Canal Lock Replacement Feasibility Study**
Julie LeBlanc, LMN

1340-1400 **Hazardous, Toxic, and Radioactive Waste Initial Assessment for a Flood Control Project in an Urban Watershed**
Cheryl Peyton, LMN

1400-1420 **Demonstration of Equipment for Dredging Contaminated Sediments at Buffalo River, New York**
Thomas Kenna, NCB

1420-1440 **Pilot-Scale Demonstration for Remediation of Contaminated Sediment from Ashtabula River, Ohio**
David Conboy, NCB

| | | |
|---|---|---|
| 1440-1500 | **Hot Spot Remedial Action, New Bedford Harbor Superfund Site**<br>Mark Otis, NED |
| 1500-1520 | **Dioxin-Contaminated Sediments, a Case Study**<br>Robin Coller-Socha, SAC |
| 1520-1540 | **Break** |
| 1540-1600 | **Biological Investigations for a Remedial Investigation/Feasibility Study, Sangamo Weston, Inc./Twelve Mile Creek/Lake Hartwell PCB Contamination Superfund Site**<br>Michael Alexander, SAS |
| 1600-1620 | **Methods for Statistical Analysis of Less Than Detection Limit Data, a Simulation Study**<br>Joan Clarke, WES |
| 1620-1640 | **Ocean Disposal of Dioxin-Contaminated Dredged Sediment from New York/ New Jersey Harbor**<br>Monte Greges, NAN |
| 1640-1700 | **Wrap Up**<br>Pete Juhle, HQUSACE |

## *Friday, 18 February*

| | |
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| 0730-1230 | **QA/QC Workshop**<br>Jan Miller, NCD |

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# Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| acres | 4,046.873 | square meters |
| acre-feet | 1,233.489 | cubic meters |
| cubic feet | 0.02831685 | cubic meters |
| cubic yards | 0.7645549 | cubic meters |
| degrees (angle) | 0.01745329 | radians |
| Fahrenheit degrees | 5/9 | Celsius[1] |
| fathoms | 1.8288 | meters |
| feet | 0.3048 | meters |
| gallons (U.S liquid) | 3.785412 | liters |
| inches | 2.54 | centimeters |
| miles (U.S. statute) | 1.609347 | kilometers |
| pounds (mass) | 0.4535924 | kilograms |
| pounds (force) per square inch | 6.894757 | kilopascals |
| square miles | 2.589998 | square kilometer |
| tons (2,000 pounds, mass) | 907.1847 | kilograms |

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32).

# Introduction

The Corps of Engineers Seminar on Water Quality is held biennially to provide for professional presentation of current research projects and operations activities. Subsequent to these presentations, the Civil Works Research and Development Program Review for the Water Quality Research Program is held. This seminar and program review are attended by representatives of the Headquarters, U.S. Army Corps of Engineers (CE); CE Laboratories and Field Operating Activities; and CE Division and District offices.

The overall objective of this biennial seminar is to provide an opportunity for presentation of water quality assessment, prediction, and control for reservoirs and inland waterways as well as coastal and estuarine water resource projects.

The printed proceedings of the biennial seminar are intended to provide all levels of Corps management with a summary of current water quality research and development as well as operational activities.

The contents of this report include the presentations of Water Quality '94, the Corps of Engineers 10th Seminar on Water Quality, held in Savannah, Georgia, 15-18 February 1994. Abstracts have been substituted for papers not provided.

# Performance-Based Water Quality Management

*by*

*Richard E. Price,*[1] *Fredrick B. Juhle,*[2] *and Dave Brown*[3]

## Introduction

The U.S. Army Corps of Engineers (CE) is responsible for operation and management of numerous water resource projects across the United States. Water quality management is a major activity at many of these projects, requiring considerable allocation of resources to achieve environmental and water quality objectives. To achieve the most efficient and effective use of resources in this era of dwindling dollars and manpower, many agencies are investigating the use of a performance-based management approach to water resource projects. This approach requires that the manager define water quality objectives in measurable and quantifiable terms, identify available resources and constraints to management objectives, execute management plans, and evaluate the success of management plans relative to initial objectives.

Although a performance-based management approach has been used in a number of areas, such as Total Quality Management approaches, it has not been universally applied to environmental management initiatives. Some water quality programs may function in this manner; however, the relationship between established management goals, monitoring, and continued assessment of progress towards the management goals is not obvious. Through performance-based water quality management, the links between management objectives, technical monitoring programs, and evaluation of success can be clearly defined.

## Performance-Based Water Quality Management

Performance-based water quality management (PBWQM) may be best defined as an approach to water quality management that includes all aspects of resource management focusing on success of the overall program rather than simple compliance to water quality criteria. In traditional water quality management programs, the resource manager identified appropriate water quality criteria for a given project. These are usually based on U.S. Environmental Protection Agency (EPA) or State standards and are designed to protect the water for a given use, such as drinking water, recreation, or fish and wildlife uses. In most cases, these are generic criteria, applicable to most any water resource. The PBWQM approach utilizes these criteria as a basis for identification of water quality problems or indicators of environmental health. However, this approach expands the objective of the managers program to include other criteria such as indicator organisms or biological indices. It also would include resource criteria, such as methods of program execution (in-house versus cooperative with other agencies), expertise of staff (academic degrees, disciplines, and professional registration), degree of public involvement in setting water quality goals (public meetings for criteria evaluation versus publication of water quality goals), communication of goals, and degree of communication.

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There are a number of advantages to the PBWQM approach.

- **Efficiency oriented**. The PBWQM is efficiency oriented, implementing a procedure for evaluating how well water quality management programs are being executed. This will provide the resource manager with methods to evaluate allocation of resources to achieve the most cost-effective enhancements to project water quality.
- **Broader based objectives**. The PBWQM is a broad-based management approach, incorporating a team approach to definition of objectives, including evaluation of management performance in the traditional evaluation of water quality monitoring. The evaluation includes performance of all aspects of the water quality management program, including resource utilization, coordination with all involved parties, and communication of objectives and management success for each project.
- **Standardized process**. The use of PBWQM will institutionalize a standardized process for identifying management and water quality goals, establishing criteria and objectives for evaluation of water quality and management of resources. This will provide a means for comparison of water quality programs between Districts and Divisions as well as comparison of individual projects over time.

## Examples of Similar Initiatives

A number of Federal and State agencies are investigating the use of performance-based management approaches. These management approaches are designed to improve efficiency within the organization, include management and resource allocation decisions in the evaluation of the technical program, and to provide a standard method for evaluation of the particular environmental program.

The Tennessee Valley Authority (TVA) Reservoir Monitoring Program (TVA 1993), which was initiated to evaluate the health of the reservoir ecosystem and determine how well each reservoir meets water quality goals of the Clean Water Act, focuses on indicators for program evaluation. Five indicators were identified for reservoir health, dissolved oxygen, chlorophyll, sediment quality, benthic macroinvertebrates, and fishes. For each indicator, scoring criteria ranging from 1 to 5 were established with a score of 1 representing a poor condition and 5 representing excellent conditions. Using this procedure, water quality, plankton, benthic, and fisheries data for each reservoir can be summarized into a numerical score to provide a general evaluation of reservoir health. These evaluations can then be used to provide the public with water quality information and can be used by managers for comparisons between individual reservoirs as well as evaluation of an individual reservoir's health over time.

As another example, the Intergovernmental Task Force on Monitoring Water Quality (ITFM) was established under the Interagency Advisory Committee on Water Data to review and evaluate water quality monitoring activities and report to the Office of Management and Budget, Federal agencies, Congress, States, and others on water quality monitoring concerns. A major objective of this task force was to develop a strategic plan for effective collection, interpretation, and presentation of water quality data to provide a more effective basis for decision making. These objectives also included application of environmental indicators and development of a water information network for data sharing. These objectives are directed at more effective communication of water quality information with the public, providing guidelines for water quality reports based on the intended audience and how well information is presented. It also calls for performance-based methods of water quality analysis. The ITFM provided input into proposed revisions of the Clean Water Act to recommend similar goals in support of watershed management in the States.

The third example of a similar performance-based initiative is the Aquatic Plant Management Self-Evaluation developed by the Aquatic Plant Control Program Evaluation Guidance Task Force established by Headquarters, U.S. Army Corps of Engineers (CECW-ON). This procedure was designed to provide aquatic plant managers with a self-evaluation checklist of the overall aquatic plant management program, including technical staff, facilities, resources, and management. Stated objectives of the Task Force for this procedure was to assess the efficiency and effectiveness of the individual programs and ensure the most efficient use of funds.

This program evaluation guidance document was designed to provide a standardized process for aquatic plant management program evaluation, providing a consistent means of assessing program strengths and weaknesses and ensuring compatibility with basic aquatic plant program objectives and philosophies. Technical considerations, such as ecological factors, developing technologies, and technology transfer, are included with management and training aspects of the program evaluation. This program is implemented as a checklist, with one checklist for each level of responsibility: project, District, Division, and Headquarters.

In short, the checklist is structured by requirements and responsibilities with the manager providing the status of each requirement in his program. Requirement categories include the following: presence of aquatic plant management plan, applicable laws and regulations, conducting annual surveys, development of public education program, certification/licensing for applicators, medical surveillance, technical knowledge, records management, reporting, budget preparation, fiscal management, contract administration, pesticide storage/disposal, safety, monitoring, local sponsor coordination, and technical assistance.

A pilot test of this program was initiated in the South Atlantic Division in fiscal year 1993 and is currently being evaluated for further implementation.

## Performance-Based Water Quality Management Process

For a PBWQM process to be effective, the process must be applicable to all projects and yet be sensitive enough to provide meaningful evaluations of management performance. The process should be structured with a single document, providing a standardized process for each project. Indicators of environmental health as well as criteria-based evaluations should be included. Criteria for ultimate evaluation of performance should include all aspects of program management and execution.

The structure for the PBWQM evaluation document should include the following requirements:

- **Project information**. This would include standard project data, such as name, location, size, authorization, and point of contact.
- **Environmental objective**. This section includes environmental and water quality objectives such as authorized water quality uses, involvement of local and State agencies in identification of environmental objectives, specific regulatory criteria, State standards or other established numerical criteria, and operational goals concerning water quality or environmental health that may be monitored or evaluated.
- **Program coordination**. This section includes the degree of coordination of the water quality program with local, State, and other Federal agencies such as public meetings held or attended to present program goals and objectives.
- **Resource utilization**. This section includes all aspects of resource utilization such as evaluation of in-house versus contract labor, facilities, training and qualifications of staff, unique expertise, and degree of technical coordination with private and academic organizations.
- **Enhancement techniques**. This section would include enhancement techniques

used by District personnel to meet or enhance water quality at a given project. Enhancement goal, structural or operational enhancement technique(s), and success of the technique would be evaluated. Unusual water quality features, such as submerged weirs, would be included in this section.

- **Water quality monitoring and assessment**. This section would include the traditional water quality monitoring program.
  - * **Data collection**, including sample locations, method by which sample locations are determined, statistical design, sample frequency, and quality control of data.
  - * **Data analysis**, including comparison of data to criteria or standards, water-use indices, indicators of environmental health, and use of risk assessment procedures or numerical models.
  - * **Reporting** of results, frequency and type of reports, distribution of reports, and coordination with other agencies or public groups.
- **Performance evaluation**. This section provides the evaluation of the water quality management program. Comparison of monitored conditions to established criteria. Comparison of overall management program to qualitative objectives. Assess changes from previous years program.
- **Special problems**. This section includes special problems such as major hydrologic events (floods and droughts), administrative changes (reorganization, etc.), or rapid changes in fiscal constraints (funding cuts, etc.) that may affect program management or execution.

## Conclusions and Recommendations

The development and implementation of a performance-based water quality management program will improve the water quality monitoring efficiency and effectiveness within the Corps of Engineers. It will provide water quality managers with a standardized procedure for evaluation of management performance and reporting including objectives that are broader based and oriented at improving efficiency.

It is recommended that a performance-based water quality management document be developed including the above-mentioned categories. Appropriate criteria for evaluation of each category of performance should be identified and quantified. The procedure should then be pilot tested at a CE project and results of the pilot test evaluated for future implementation.

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# "Partnering" for Technology Transfer in the Corps

*by*
*Harold T. Sansing*[1]

## Introduction

Over the past 20 years or so, the Corps of Engineers has invested resources in water quality and other environmentally related Research and Development (R&D). The implementation of these R&D efforts at the field level results in savings and technical improvements at Corps projects. The Nashville District has utilized several research packages in water control/water quality management activities as well as the consulting services of the U.S. Army Engineer Waterways Experiment Station (WES) for these and other environmentally related activities.

The R&D products from the Dredged Materials Research Program (DMRP), the Aquatic Plant Control Research Program (APCRP), the Environmental Water Quality Operational Studies (EWQOS), and more recently the Water Quality Research Program (WQRP) have all made contributions to the management of the Nashville District's system of multiple-use dams and reservoirs.

Basically, the driving force behind these research needs was the mandates set down in a series of Federal environmental and water resource management laws and regulations beginning with the Clean Water Act in 1968. The real or substantive requirements of these new environmental laws soon overshadowed the way the Corps was doing business. That is to say, the new laws required the Corps to refocus on the technical aspects of engineering projects and re-examine those original project purposes and management objectives for which we are responsible.

## Technology Development

The R&D programs mentioned above did not just "come about" nor were they thought up in an esoteric academic environment by engineers and scientists. Indeed, they were developed from scrutinizing needs and priorities identified in the field through surveys and workshops held throughout the Corps. Periodic reviews by the Committee on Water Quality and Field Review Groups maintained continuity and updated needs. As the R&D progressed, many Districts were paralleling the ongoing research by developing environmental and water resources engineering (EWRE) expertise on their own and putting together databases from projects in all phases of development.

As knowledge of Corps projects increased through basic research at the WES laboratories, so did the learning curve of the people working hands-on with the projects in the field. This field experience is very broad in scope and overlaps many technical disciplines. The combined knowledge and experience accumulated over this period represents a major bank of technical assets to the Corps.

The Corps has reached the point, however, where extensive technical and political coordination on any project undertaken is a must. Without proper coordination on the front end, a project will invariably suffer delays and unnecessary expenditures of time and resources. It has become self-evident that the environmental and water resources management community, of which the Corps is an integral

[1] Chief, Water Quality, U.S. Army Engineer District, Nashville; Nashville, TN.

partner, is ready for and must develop a real, hands-on partnering arrangement.

## Partnerships

### Primitive Partnerships

Partnerships are nothing new. Marriages have been taking place for centuries. A characteristic of human culture is that they are always cutting deals and making trades. If all parties in the trade end up feeling like humans got something for nothing, then the trade was successful—which is value added and is essential to partnerships.

### What Is a Partnership?

By definition a partnership is as follows: "An explicit agreement between two or more entities in which each consents to furnish part of the resources required for the enterprise and by which each shares in the profits and losses."[1] One can develop a simple model from this definition.

### Partnership Linkages

Partnerships represent linkages that are needed in order to save costs and reduce redundancy. What is more important, partnerships serve as value-added instruments while meeting the needs of overlapping management goals. Key elements of partnership linkages are as follows:

Shared Visions and Goals
Shared Responsibilities
Shared Costs
Shared Benefits
Shared Control

## The Problem

There is one aspect within the overall technology transfer process that needs further development. The following discussion will point out communication problems that interfere with the smooth delivery of R&D products. Improvements in delivery of these products to the marketplace will better serve the needs of Corps customers (and partners).

The obvious question is what exactly is the Corps role in the water resources management community of which it is an integral part. In the case of the Nashville District, this is self-evident based upon its Federal management responsibilities within a functional system consisting of navigation, hydropower, flood control, and recreation projects. It is important to recognize, however, that the water quality of all of the projects making up this system are at the mercy of the water resources programs and management actions of fellow members of the water resources management community composed of local, State, and other Federal entities.

Here's the situation: The Corps has a tremendous capital resource investment in technical knowledge residing in experience and research that is not being fully developed. At WES, research has been programmed over several years encompassing the DMRP, APCRP, EWQOS, and WQRP. A real alphabet soup of environmental acronyms!

The nature and size of the various R&D programs required that they be funded and administered in separate manageable units. This "separateness" has had a tendency to bias the perception of customer service needs. "In the field," the products of the various research programs and units actually cross impact and interact, physically, chemically, and biologically.

## Partner Identification

The Corps public relations efforts thus far have emphasized identifying customers or

1 Siderelis, K. (1993). "GIS data partnerships: Linking GIS data users," Tennessee GIS Users Forum, North Carolina Center for Geographic Information and Analysis.

"partners" and working with counterpart "turf" elements within their organizational structure. These counterparts more often do not even exist, so that it ends up being some kind of "force fit" and may be even counter-productive to effective communication at the technical level. This may also be confusing to a State organization, for example, whose environmental mandates are much broader in scope.

As an example, here is a rundown of the State of Tennessee's functional organization chart of the Tennessee Department of Environment and Conservation (TDEC):[1]

Bureau of Administrative Services (6 Divisions)

Bureau of Resources Management (10 Divisions)
- Construction Grants and Loans
- Recreational Services
- Solid Waste Assistance
- Archaeology
- Ecological Services
- Geology
- Indian Affairs
- Land Reclamation
- Historical Commission
- Conservationist Magazine

Bureau of Environment (10 Divisions)
- Air Pollution Control
- DOE Oversight Division
  - (Oak Ridge National Labs)
- Training Center
- Ground Water Protection
- Petroleum Underground Storage Tanks
- Radiological Health
- Solid Waste Management
- Superfund
- Surface Mining
- Water Pollution Control
- Water Supply

Under the TDEC are also 10 field offices and Pretreatment Coordinators located in virtually every town and city in the State. The multidisciplinary professional staffing of the TDEC totals some 800 personnel.

The above does not include the Tennessee Wildlife Resources Agency, which is made up of Regional Offices, technical and enforcement staffs, hatcheries, State lakes management, and others. The agency has a total staff of 568 made up of biologists, wildlife officers, and legal and administrative personnel. The agency is responsible for administering the Fish and Wildlife programs in the State.[2]

The Nashville District, with designated water management responsibilities within the Tennessee and Cumberland river basins, overlaps seven States. Assuming these States have similar environmental organizations as noted for Tennessee, one can see a real problem with communicating any kind of effective partnering arrangement in a one-on-one relationship. And from the States' viewpoint, they are facing a similar communication problem with the various Federal agencies and programs with which they must interact.

## An Approach

Given the above, a truly successful partnering arrangement poses a real challenge. Ideally, such an arrangement might consist of a primary focal group with a makeup of the vested environmental interest(s) of local, State, and other Federal management agencies. There would also be a technical link to the regional engineering and scientific (E&S) academic community. The charge of such a partnering arrangement would stress "round table" communication so that each member definitely understood the other members' charter responsibilities within the environmental and water resources management community. The group should be empowered to make recommendations affecting environmental and water resources management of the region.

The overall Corps R&D effort is not complete until it has reached full circle back to the origin of need. The key to the success of this effort is the utilization of academia as a technical extension of the District. The presence of the E&S academic community as a

[1] Directory of Tennessee Department of Environment and Conservation, Functional Organization, 1993.
[2] Personal Communication, 1993, R. Hatcher and N. Bates, Tennessee Wildlife Resources Agency.

full partner in a focal group is essential and would function as a technical oversight element. This academic partner serves as a vested interest technical "consultant" and interface for the District. This arrangement would serve to smooth out the technology transfer of research from the Corps laboratories to application in the field.

## A Continuity Model

The following outline suggests a phased process leading to the implementation of partnering and technology transfer of R&D products.

### Awareness

Consists of surveys, joint workshops, establishing triangles of technical communications involving Corps R&D Products (Labs), Districts, State, other Federal and Academia.

### Environmental Systems Requirements

Defines uses and limitations, standards, and resources.

### Environmental Systems Evaluation

Defines who manages what, cross impacts on water/natural resources/land management, management responsibilities, agreement on environmental systems component definitions and priorities (land usage BMPs, CSOs, point, nonpoint, critical Qs, cross impacts).

### Implementation Plan

Defines priorities, benefits, value added, joint management agreements.

### Partnering

Consists of joint operational phase with periodic review. Empowerment of local, regional "teams" committed to Total Quality Management (TQM) of the environmental systems components.

## District Partnering

The Nashville District has been fortunate in having the opportunity to gain experience in the pursuit of partnership arrangements. The following are brief examples.

### Interagency Management

As far back as 1987, the District orchestrated a partnering meeting of the "natural resource managers" in the central region of Tennessee. The reasons behind the partnering arrangement stemmed from accusations and the suspicion of "pollution" occurring at a top recreational lake situated within the Caney Fork River Basin. Much time and resources can be easily misdirected as a result of "emotional science" that sometimes tends to gloss over facts and leads to dead-ends.

The District started an initiative to discover the facts of the case. We proceeded with identifying and researching the responsibilities of those agencies who had any kind of natural resources management responsibilities within this river basin. These agencies were all informed of the situation and invited to participate in a round-table discussion of the subject. Academic expertise of the region was also researched and asked to participate as vested expert witnesses.

The round-table meeting was organized much in the fashion of a workshop. The makeup consisted of some 12 official members representing State and Federal agencies and academia all of which play a resource management role in this region. A Discussion Paper was developed by the District that induced participation by all members of the group. Each group member was a manager of an agency function that could be responsible for generating point and nonpoint sources of contaminants generic to the management of the water quality of this lake project.

From the Discussion Paper came an outline of possible sources of contaminants that could impact the water quality of this recreational project. Some action alternatives were proposed. The most important aspect of this meeting was the information and knowledge gained by each participant. Many of the persons in the meeting were literally unaware of the others' specific management responsibilities and the impacts their actions had on the water quality and recreational potential of this lake project. The "partnering" was a total success from a standpoint of information trade exchange and served to build confidence and candidness for future meetings of this nature.

### Regional Environmental Engineering

The Nashville District recently completed a reconnaissance report entitled the "Metropolitan Nashville Regional Environmental Engineering Study, TN." The study area encompasses three lake projects managed by the District. The projects are managed for navigation, flood control, hydropower, and recreation. The discharges from these projects supply water to a system of multiple uses and stream-use classifications including water supply, water quality, fish and wildlife, and recreation. The projects also receive discharges from point and nonpoint sources within the region.

The study focuses on the interdependency of water uses in the region and demonstrates the changes that have occurred as a result of the development of the Cumberland River System. It presents a great challenge to the engineering community to develop a regional water resources management design to fulfill the requirements of environmental regulations of air and water pollution control. Partnering will have to play an important role from a technical and social as well as a financial standpoint.

### Tennessee Rivers Information System (TNRIS)

The District is now a partner with the TDEC in development of a comprehensive, statewide rivers assessment. The result of this effort, the TNRIS, will consolidate information for various river-related resources into a master database residing on a Geographic Information System (GIS) with unlimited retrieval options. Participation in the rivers assessment has come from a diverse group, including Federal, State, and local individuals. Each participating entity is either contributing its expertise and/or funding a portion of the effort. The investment of these partners in the TNRIS will be returned many times over as a result of having access to such a powerful decision-making and planning tool. Corps of Engineers applications for the TNRIS include natural resource management, regulatory permitting actions, and project planning.

## Conclusion

Facing the new environmental and water resource engineering paradigm will always be a real challenge to our engineering capabilities. Incorporating its unfamiliar technical requirements into the way we do business poses a challenge for R&D and management alike. It also presents us with great opportunities in a world of changing roles and new partnerships.

# The Nature of the Beast

*by*
*John L. Andersen*[1]

## Introduction

Water quality in a District office involves working with a wide variety of problems and opportunities. Many of these problems and opportunities may not come under the purview of water quality as defined by various regulations, manuals or individuals, yet definitely belong in the area of endeavor broadly defined as water quality. It should be noted that the "purview" of water quality may vary widely from District to District ranging from doing very little to conducting numerous studies and managing complex sampling programs and water control situations. Because of the wide range of activities, it would perhaps be more appropriate to change the name "water quality" to "reservoir ecology" or "aquatic engineering" to more accurately define the job. During the past few years, a sampling of tasks performed by water quality personnel that often do not come under the strict definition of water quality (this varies from District to District) include the following: (a) urbanization and associated problems; (b) sedimentation problems associated with agriculture, construction, or shoreline erosion; (c) fisheries; and (d) education as it relates to environmental awareness and the continued quality of Corps projects for their assigned purposes.

## Urbanization

Urbanization is a major problem facing many Corps reservoir projects. Unfortunately, problems associated with urbanization are often dealt with on a crisis management or piecemeal basis. Under this scenario, once a problem is handled in a particular manner, a precedent may be set that limits future options or can make future changes in handling similar problems difficult. In addition, the urbanization can be extremely damaging to reservoir ecology, recreation, and project longevity. Urbanization problems associated with water quality are basically two types; those associated with the construction period and those associated with post construction.

Construction methods normally involve laying the land bare, thus allowing sediment-laden runoff to impact nearby streams and reservoirs. Personal observation indicates that Best Management Practices (BMPs) to minimize construction-associated sedimentation damage are rarely used. Obviously, there are methods of minimizing this type of impact: temporary sediment ponds, staging construction, etc., so that large areas are not denuded, using bales or sediment curtains, etc. It is suggested that (BMPs) be mandated for Corps contractors and project sponsors. In addition, every effort should be made to prevent off-project construction sedimentation from causing on-project impacts. This could be accomplished by working with developers and appropriate State agencies.

Postconstruction problems are commonly associated with storm drainage and urban pollution. The conversion of grasslands or forests to roads, roof tops, sidewalks, and other water-impervious surfaces makes stream flows more variable and increases the frequency of flooding (U.S. Environmental Protection Agency 1972). In addition, pollutants associated with urban drainage can cause severe impacts to downstream water bodies (Whitman 1968). Urban storm flows detrimental to receiving waters can be permitted under the National Pollutant Discharge Elimination System

[1] U.S. Army Engineer District, Omaha; Omaha, NE.

(NPDES) thus requiring treatment. Storm sewer exits can be allowed on project lands provided that the developer will go to some effort to provide detention in the form of ponds, swales, or wetlands on private property. In addition, the developer might be asked to construct a series of wetlands to slow downhill flows and provide time for bacterial die-off, chemical degradation, reduced flow rates, and sedimentation. The advantage to the developer would be the construction of the storm sewer outlet on property that may allow for an extra structure or more aesthetic conditions on the property being developed. (It is important to note that "wetland" as defined for purposes of this paper is a shallow basin not more than 1 to 2 ft in depth and filled with aquatic plants.) It should not be defined as a pond that, under some conditions, can be considered as an attractive nuisance.

There are numerous methods of minimizing urbanization impacts; however, these methods are rarely considered. Very commonly, those reviewing drainage plans are individuals familiar with hydrology but unfamiliar with the environmental problems associated with drainage. Obviously, these groups should work together, not independently.

It is suggested that an organized process or policy be created within each District to handle urbanization problems in a reasonable and consistent manner. Such a policy should involve water quality, natural resources management, engineering, and other forms of expertise and should work with developers to reach agreement as opposed to simply accepting whatever damages might occur. A variety of scenarios could be developed, their primary purpose being to maintain the quality, longevity of the project, and good relations with urban interests. Such actions would be beneficial to both parties.

## Fisheries

In many Corps Districts and Divisions, fisheries are considered a function of the State and thus receive scant attention in terms of water quality, baring of course a situation where releases or some other Corps activity is seriously impacting a valued fishery. However, fisheries can be an excellent indicator of both water quality and the ecological health of a reservoir. A fish kill for instance is a clear indicator that something is wrong. In terms of water quality, it may not indicate what is wrong but serves as a cue to start looking. Because of bioconcentration, testing for pollutants in fish flesh is often more productive than testing for lower pollutant concentrations in water. The loss of or a significant change in the fishery over time can be a clear indicator of problems even though continued testing or water quality sampling and comparison of results to existing standards indicates no particular problem. An example of a problem occurring over a period of years undetected by water quality sampling and analysis, or any other District effort, would be the loss of the bass-bluegill fishery in the Salt Creek Reservoirs located near Lincoln, NE.[1] (The Salt Creek Reservoirs are a system of 10 flood control reservoirs constructed by the U.S. Army Corps of Engineers during the early to mid 1960s.) While records of the fishery in the Salt Valley Reservoirs are sporadic, it was obvious by the 1980s that the bass-bluegill fishery was no longer a viable recreational fishery. In addition, data obtained during the 1991-1992 period compared with data obtained during 1968-1970 indicated that benthic populations decreased by a factor of 10 (Popp 1993). Sedimentation had covered the habitat needed for a viable bass-bluegill fishery and had also destroyed a major part of the benthic community, a significant part of the food web. Visual observations over the

[1] Schainost, S. (1989). "Further investigations into the largemouth bass population dynamics of the Salt Valley Reservoirs," Unpublished Final Report, Project No. F8112, Nebraska Game and Parks Commission.

years indicated that increased turbidity associated with sedimentation had essentially eliminated macrophytic vegetation.

Within a time span of 10 to 15 years (a very brief time in the life of a reservoir), a major fishery was lost, a benthic community was lost, and a major portion of the macrophyte community was lost; yet no one can point a finger at any segment within the District structure and say, "You failed to do your job." It is obvious that something is missing in the engineering, design, and management of our reservoirs. Fisheries should be utilized as an ecological tool in the management and operation of our reservoirs.

## Education

Reservoir management within the U.S. Army Corps of Engineers tends to be piecemeal. One agency manages the fishery, another agency or part of an agency manages grazing leases, another part of an agency maintains camp pads or grass mowing, and still another part of the agency looks at water quality, etc. Even if all the management parts perform their function perfectly, the reservoir still suffers because it is considered as distinctly separate parts, pieces, and responsibilities. Rarely is a reservoir considered as an ecological unit; because of this, reservoirs and their recreational and ecological functions are being unnecessarily lost.

A significant portion of the water quality effort in a given District should consist of education in terms of reservoir management. In the event that education is not deemed to be a function of water quality, then a separate unit, group, etc., should be established to look at the reservoir and its watershed as an ecological entity and actively interact with the appropriate organizational elements to properly manage the reservoir. Unfortunately, the bureaucracy is not set up to handle such an effort. It should be obvious that significant ongoing shoreline erosion is a serious problem that will result in severe ecological damage, thus limiting recreational and aesthetic value. This problem should be funded and handled in a systematic and scientific manner as opposed to simply purchasing additional lands or utilizing rock to protect only constructed facilities or cultural resource sites.

The Omaha District has thousands of miles of ongoing shoreline erosion yet systematic efforts to resolve the problem are piecemeal or nonexistent. Those few projects that have been completed are rarely monitored over a period of years for success or failure. As a result, failures are repeated and often successes are not repeated.

Tens of thousands of acres of wetlands have been lost within Omaha boundaries (through no fault of the Corps), yet efforts to create or establish wetlands to improve water quality or to produce waterfowl are miniscule and often accomplished only with heroic efforts that of necessity must circumvent established procedure.

One ranger approached the District office in an attempt to get some small ponds constructed for purposes of rearing waterfowl and because he was concerned about agricultural drainage. The District design costs alone would have destroyed his entire annual budget. In desperation, he approached a contractor he knew and asked what it would cost to construct the ponds. The ponds were designed and constructed for $2,500 each. The ranger, in order to accomplish the simple goal of building some ponds, was carefully trained to avoid the Corps bureaucracy. It's easier to ask forgiveness than permission.

Environmental problems on Corps projects are all too common. Low cost, low tech solutions are all too common. Yet the concrete and steel mentality rules and little gets accomplished because it's "too expensive," or new ideas are dismissed with a cursory "Can't be done."

The bottom line? We simply don't get it.

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# High-Speed System for Synoptic Assessment of Riverine Near-Surface Water Quality Conditions and Spill Response

*by*

*William L. Cremeans,[1] Richard M. Meyer,[1] and George P. Kincaid[1]*

## Chronological Perspectives and Development of the Initial System

Development of the system discussed in this paper was begun during Huntington District's response to a massive spill of diesel fuel that entered the Ohio River in January of 1988. By most estimates, nearly one million gallons[2] of Number 2 diesel fuel were released. The spill posed substantive threats to water-treatment plants, many water users, and aquatic life along hundreds of miles of the upper Ohio. To minimize impacts to the greatest extent possible, the primary task of the various agencies responding to the spill was to provide ongoing definition of the location and extent of the spill.

### Fluorometers

Fluorometers were quickly identified as the most practical means of tracking the spill. They could provide both sensitive and instantaneous response to aromatic and polynuclear aromatic components of the diesel fuel that are capable of fluorescing, such as benzene and naphthalene.

Laboratory-model fluorometers were the first type used in attempts to ascertain the leading edge of the spill. A towboat transported investigators along the river to collect grab samples, which were then placed in cuvettes for analysis.

### Pumped-Water Systems

As the spill approached Hannibal Locks and Dam, the uppermost extent of Huntington District, our Water Quality Section assumed responsibility for tracking the spill. Equipment used included a field-portable Turner Design Model 10 fluorometer, which was configured with a flow-through cell and interfaced with a strip-chart recorder. The equipment was used aboard a 23-ft workboat capable of cruising at relatively high rates of speed.

The flow-through cell was first used in conjunction with a water intake provided by a weighted submersible pump attached to a garden hose. This arrangement could be towed only at very low speeds, about 2 to 3 miles per hour, but did provide continuous monitoring. The pump could also be lowered from river surface to bottom to evaluate possible layering of petroleum products.

In an effort to gain greater speed for tracing the spill, the submersible pump was next housed within a towable "fish" constructed of polyvinyl chloride (PVC) pipe and aluminum, an arrangement that allowed a maximum cruising speed of about 8 miles per hour. This system was used successfully at approximately 5 miles per hour and proved ideal for near-surface cross-sectional profiles and definition of mixing zones near tributary streams.

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[1] U.S. Army Engineer District, Huntington; Huntington, WV.

[2] A table of factors for converting non-SI units of measurement to SI units is presented on page xxi.

With the strip-chart recorders, continuous traces of the relative longitudinal concentrations of spill materials were possible, and the leading edge of the spill and the zone of maximum contaminant concentration could be defined for the reach of river traversed by the boat. River-mile positions were determined by the pilot using charts, navigational aids, and landmarks and transcribed to the strip charts. These traces, as reproduced in Figure 1, delineated the spill's spatial distribution and were very helpful in predicting next-day conditions for downstream water users.

cern was that the spill might easily outrun the towable-fish system.

By an evolutionary thought process, the idea occurred to use the forward motion of the boat to force near-surface water through tubing to the instruments mounted aboard the boat. The concept was tested using a 3-ft length of 3/4-in. copper pipe. With the boat on-plane, the hand-held pipe was oriented at an angle of about 45 deg parallel to the vessel, with the lower end facing the axis of water flow. When the tip of the tubing was inserted into the river, the resultant

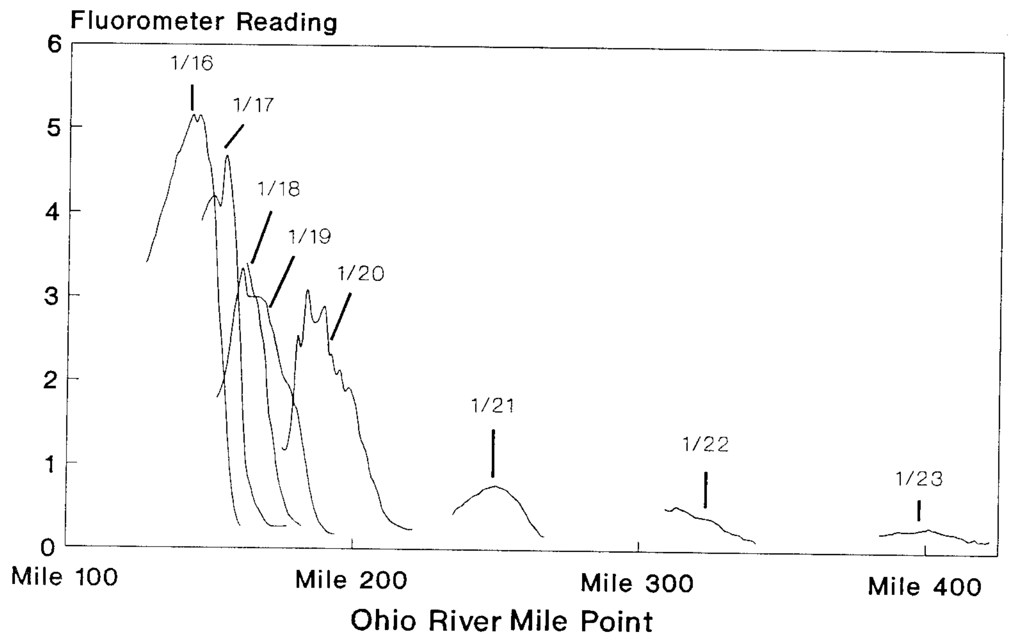


*Figure 1. Spill configurations, January 16-23*

## Forced-Water Systems

Limited daylight hours allowed the sampling team only enough time to find the spill's leading edge and the zone of maximum contaminant concentration. To further complicate matters—with the onset of warm weather, melting ice and snow, and rainfall—Ohio River flows and water velocities significantly increased on January 19. The need to find a monitoring method that would allow a faster cruising speed for the boat became compelling. A major con-

jet of water reached a vertical height of about 10 ft.

## High-Speed Monitoring

A depiction of the final forced-water (flow-through) system is shown in Figure 2. Sections of 1/2-in. stainless steel pipe and fittings were affixed to the keel and transom of the work-boat to form a large "U." A 4-in. section was secured under the stern facing the bow. In this configuration, the forward movement of

the boat (on-plane) forced water through the tubing to the monitoring system and outlet for sampling. A ball valve was installed in-line to restrict the pressure reaching the fluorometer flow-through cell to less than 25 psi, at a cruising speed of ±30 mph.

By using this continuous-flow system, routine monitoring was rapidly completed. First, the boat was run downstream past the spill until ambient conditions of river fluorescence were reached. Then the vessel was turned and headed upstream at a cruising speed of about 30 mph. Critical features of the spill—such as location of the leading edge, the zone of maximum contaminant concentration, and conditions upriver—could be defined within 1 hr.

As discussed below, the experience gained from this incident has influenced our philosophy for monitoring large-river systems.

## Drought Monitoring and Use of Flow-Through System Modifications

The summer of 1988 presented Huntington District's Water Quality Section with yet another problem related to monitoring rivers. A drought occurred in the Kanawha River Basin.

### Drought Effects and Low-Flow Augmentation

Several Corps lakes in the basin provide, as a project purpose, flow augmentation for pollution abatement. During the low-flow conditions of 1988, concern existed that water reserved for augmentation at these projects might not last through the period of drought. Releases for augmentation impacted other project purposes, including recreation and

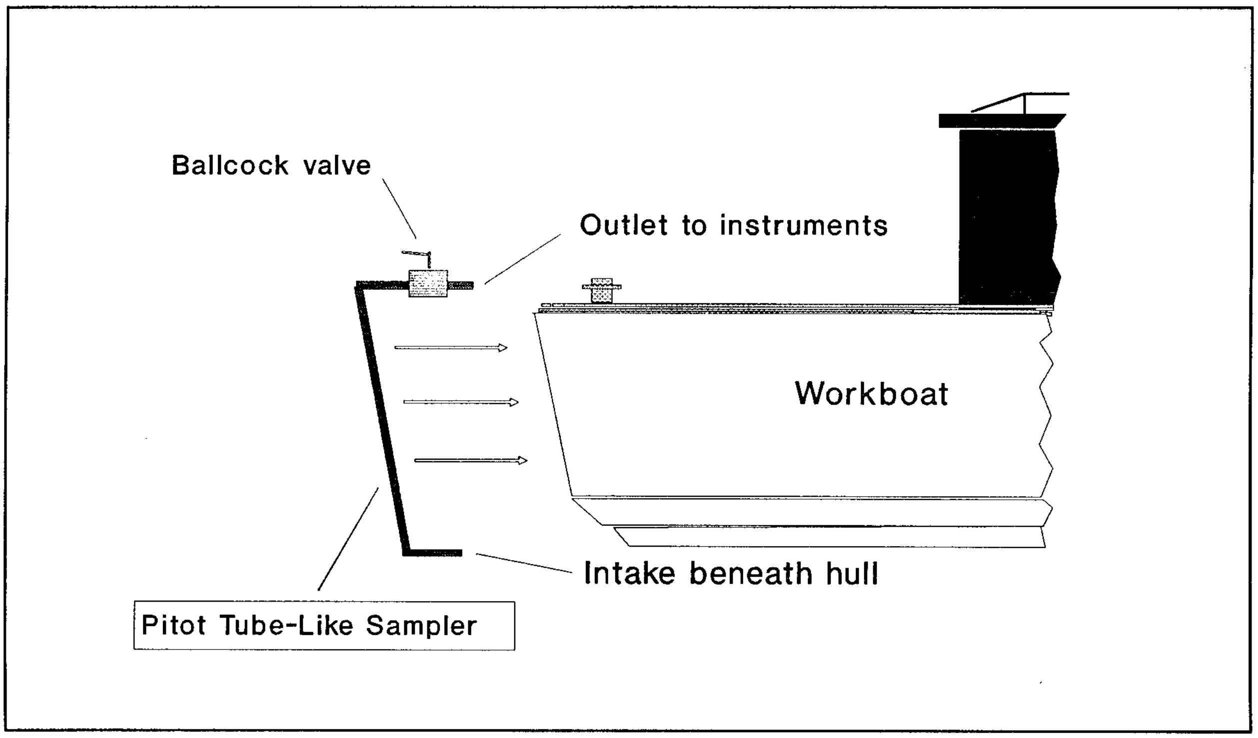


*Figure 2. Flow-through sampling system using a pilot tube-like device*

water supply. At the same time, chemical industries along the Kanawha River near Charleston, WV, were threatened with shutdown as river flow and dissolved oxygen levels declined. Additional demands on the limited water resources were created by the white-water rafting industry, a profitable source of tourism in the state.

Based on District concerns and perspectives related to impacts of diminished flows in the vicinity of Charleston, we initiated work efforts to evaluate water quality conditions in the Winfield pool. This required additional water quality sensors and further refinement of the system used to monitor the diesel-oil spill.

## Additional Water-Quality Sensors and System Refinements

The instrument package configured for monitoring low-flow conditions in the Kanawha River included the following: (a) one Turner Model 10 Fluorometer configured to monitor primary productivity by measurements of chlorophyll-*a*; (b) one Turner Model 10 Fluorometer configured to monitor turbidity with a nephelometer cell; (c) one Hydrolab Datasonde II to monitor water temperature, dissolved oxygen, pH, and specific conductance; (d) one Crodata Model 1680 Datalogger to record fluorometer data; and (e) one Zenith Model 180 laptop computer to record Hydrolab data by means of RS-232 communications protocol at 5-sec intervals. Event marks, field notes, and synchronized times were recorded to ensure time alignment of databases.

Fluorometers had provided reliable data utilizing the flow-through system during the spill response, but Hydrolab response characteristics were untested. When the datasonde was initially installed in the flow-through monitoring system, for purposes of evaluating relative accuracy of instrument readings, data were collected from a stationary boat and from a boat on-plane at cruising speed. The results were reassuring. While the flow-through data included nominally higher concentrations of dissolved oxygen than readings from a stationary boat, the pattern of resultant flow-through data matched the pattern of data collected under stationary-boat conditions.

## Monitoring Activities

Satisfied with test results of instrument response, 90 miles of the Kanawha River and the area of its confluence with the Ohio were surveyed. All parameters were recorded at 5-sec intervals and averaged to compute a value for quarter-mile sections of the river. Averaging of this enormous amount of raw data was performed to accommodate limitations of the plotting program.

Using this system to monitor river conditions once or twice each week provided data to water users and regulators on nearly a real-time basis. Initial results of the monitoring forced a reevaluation of factors affecting the dissolved-oxygen budget of the Kanawha River, and the manner in which waters from the lake projects are used.

## Changes in Water-Quality Conditions and Flow-Augmentation Criteria

With the remarkable improvements in water quality of the Kanawha River over the last several decades, aside from the influences of flow, the primary factor governing dissolved-oxygen concentrations is populations of aquatic plants. Yet, established guidelines for releasing flows from all basin reservoirs during low-flow conditions depend upon temperatures measured at a single point. The basis for these guidelines is a relationship between temperature and dissolved-oxygen concentrations established in the 1960s.

Since the establishment of the guidelines, however, curtailment of industrial and sewage discharges have greatly reduced oxygen demands and greatly improved water quality conditions in the Kanawha River. Pressures exerted by various water-user groups and the public indicate that the need exists to revise

the current guidelines to reflect contemporary conditions.

## Advantages of Continuous-Flow Data

The use of continuous-flow data has many advantages compared with readings that are taken at single locations by boat under stop-and-go conditions, from bridges that limited available locations, or collected when sampling intensity and location are dictated by time constraints. For instance, Figure 3 is a graph of dissolved oxygen concentrations for 90 miles of the Kanawha River. The asterisks represent the data that would have been collected from bridges with 1 day's effort. Overlaying results of the continuous-flow data with geographical features and locations of water-user intakes and discharges yields an amazing insight into effects of industrial discharges and tributaries on the river system. For example, the locations of electric power-plant discharges are readily obvious from temperature data, as are the locations of some tributaries from conductivity data.

## More Low-Flow Conditions, Updating of System Components, and Accuracies of Dissolved-Oxygen Probes

In 1990, low-flow conditions in the Kanawha Basin again resulted in the need for water-quality monitoring. Since another generation of Hydrolab instruments was in use by the Water Quality Section, a series of flow-cell related tests were run on new equipment. A Hydrolab Scout II with flow-cell configuration was tested for accuracy of dissolved-oxygen measurements.

### Use of Test Tanks

First, responses of the dissolved-oxygen probe were evaluated under simulated flow-through conditions at different dissolved-oxygen concentrations. Water in a test tank was well-circulated, and dissolved-oxygen concentrations varied by adding small amounts of sodium hypochlorite. As shown in Figure 4, test results were excellent.

### Flow and Pressure Tests on Boat

Second, the dissolved-oxygen probe with flow-cell was integrated into the flow-through system on the boat and tested for response to flow variability. Dissolved-oxygen sensors are known to be very sensitive to pressure changes, which can affect the transfer of oxygen across the semipermeable-membrane component of the probe. The first step in this test was to traverse a 2-mile reach of the Ohio River while collecting measurements of temperature and dissolved oxygen, with the ball valve used to regulate for a low constant flow and pressure to the Hydrolab Scout. The unit was found to have constant, stable responses under conditions of constant flow and pressure.

Next, the same reach of the river was again traversed several times while flow to the dissolved-oxygen sensor was incrementally increased using the ball-valve. In this manner, instrument response to a wide range of flows and pressures was measured. The deviation from known concentrations, about 0.3 mg/L, was found to be constant and relatively insignificant.

### Tests with Cross-Calibrated Instruments

During the 1990 study, assistance was given to the Corps by the West Virginia Department of Natural Resources (WVDNR). A WVDNR workboat was used to ascertain the accuracy of surface readings collected by the flow-through system on the Corps boat after Hydrolab units from both agencies were cross-calibrated. The two water craft traveled together until sudden changes or significant decreases in dissolved oxygen were indicated by the flow-through system. At that point, a marker buoy was thrown from the Corps boat. Staff of WVDNR circled back to the marker and took in situ measurements at marker-buoy

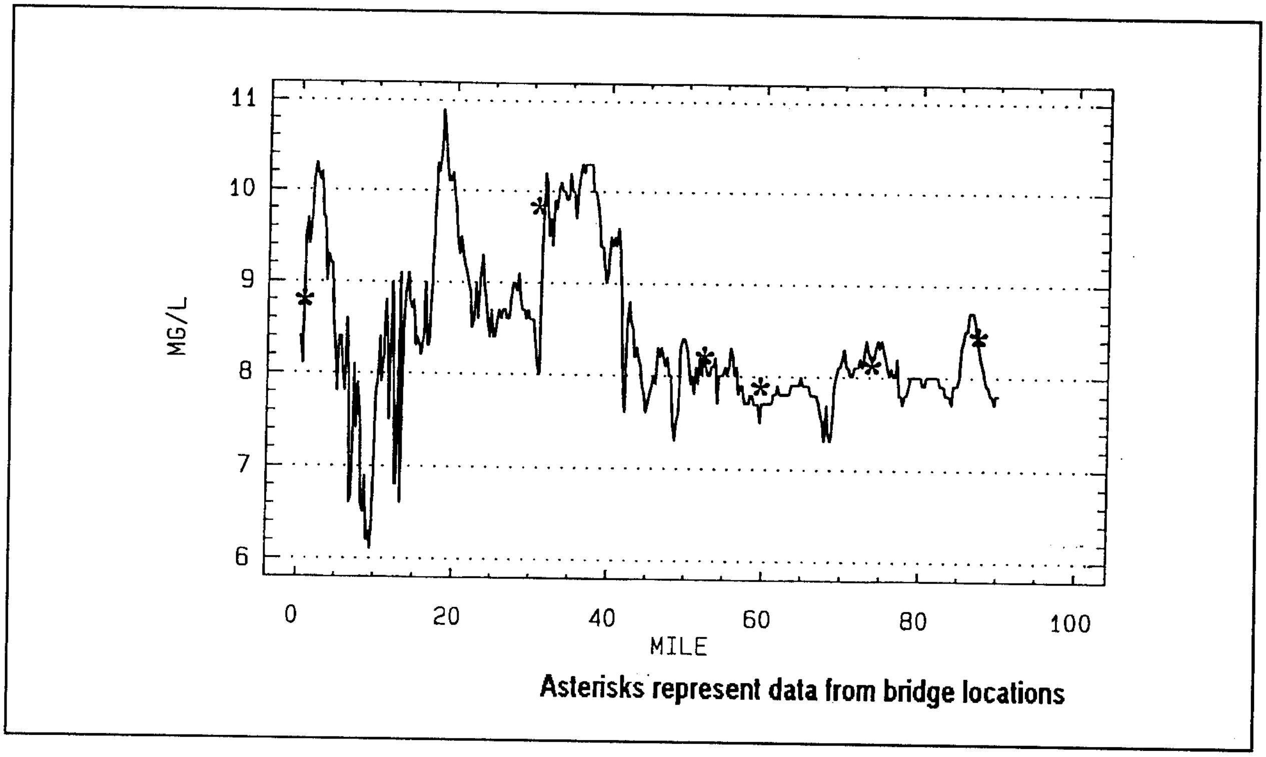


*Figure 3. Kanawha River, dissolved oxygen, 17 August 1990*

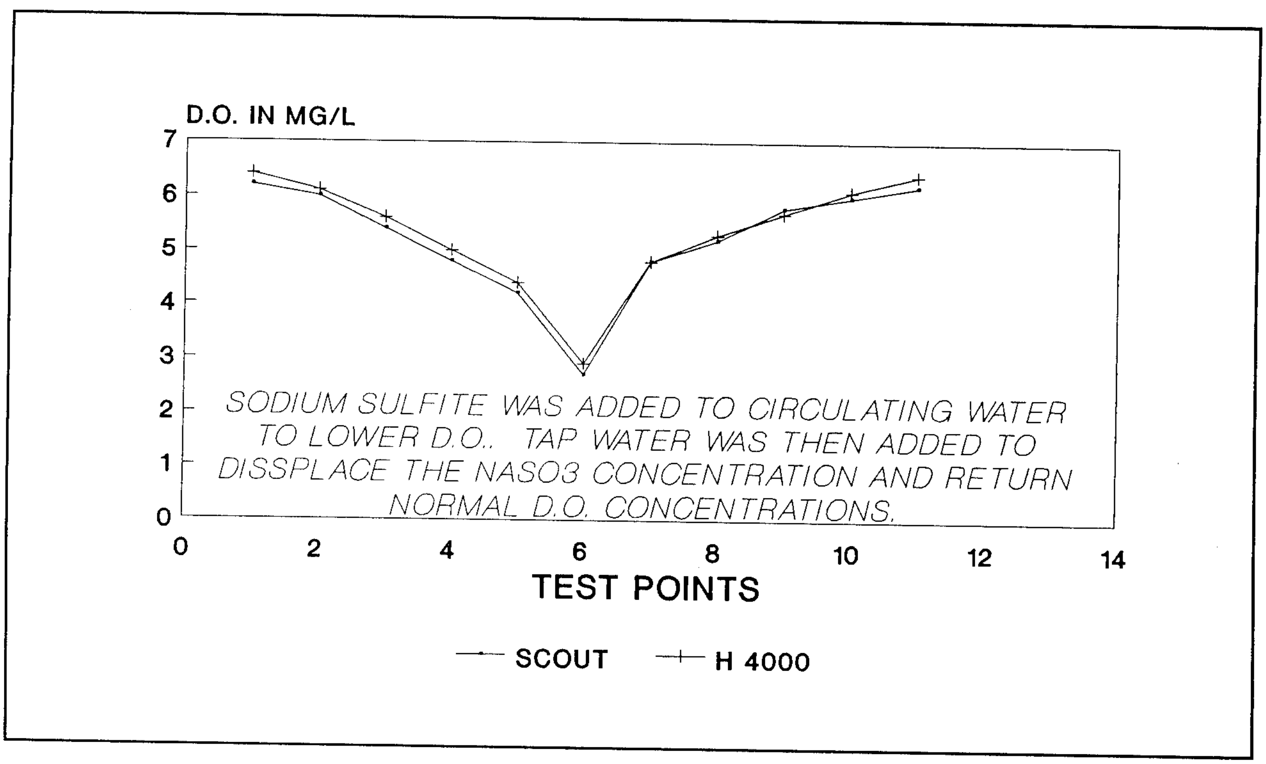


*Figure 4. Scout/flow cell test (tested against H4000)*

locations. The complementary sets of dissolved oxygen measurements showed remarkably close agreement.

## Where We Are Now

### More Instrument Changes

Changes have occurred in all instrumentation involved and considerably enhanced system flexibility. The following are examples:

- Turner Fluorometers (Model 10-AU-005) have increased signal output options, allow variable range selection with warning alarms, and have internal logging capability.
- Hydrolab Corporation has produced several models available with SDI-12 communications protocol, RS-232 protocol, and an internal logging capability.
- Stand-alone dataloggers, such as those from Campbell Scientific, offer the ability to integrate signals from many instruments and to produce real-time output of information to graphic screens from a multitude of sensors.

### Cautionary Words

Words of warning are warranted to safeguard potential users of combined instrument systems of the type described above. Most individual instrument components have not been designed with high-speed, continuous-flow systems in mind. Some instruments may have sensing probes with slow response times, some instruments may "power-down" sensors between measurements, and some instruments simply may not be suitable under any circumstance with the demands of forced-water flows and pressures. To ensure successful integration of the various instruments into one fully functional system, close coordination between the users of these systems and the instrument manufacturers is absolutely mandatory.

### System Now in Use

Currently, Huntington District Water Quality personnel are using the following instruments:

- One Hydrolab H20 water quality monitor with SDI-12 communications protocol and internal batteries installed to maintain sensor polarization.
- Two Turner Designs Model 10-AU fluorometers.
- One Campbell Scientific CR-10 datalogger with optional graphic software for continuous-flow monitoring.

With this system, Chlorophyll-*a*, turbidity, temperature, dissolved oxygen, percent saturation of oxygen, pH, and conductivity are graphically displayed on a laptop computer in real-time. Figure 5 is a screen-captured graphic of data as it is plotted. The continuous plots are equivalent to strip-chart recordings. In addition, incoming data are displayed as updating bar charts with labeling to serve as an instantaneous reference. The scaling range for plots may be set to automatic or manual, but does not alter data values if over-ranging occurs.

### New Additions to the System

Inclusion of Geographical Positioning System (GPS) data to enhance accuracy of determining boat location and speed is the next planned addition to this system.

### Use of Remote Sensing

River investigations are planned to provide continuous near-surface measurements of temperature, dissolved oxygen, pH, specific electrical conductance, turbidity, and chlorophyll. These measurements will be made along selected reaches of the Ohio River and along navigable reaches of selected tributaries.

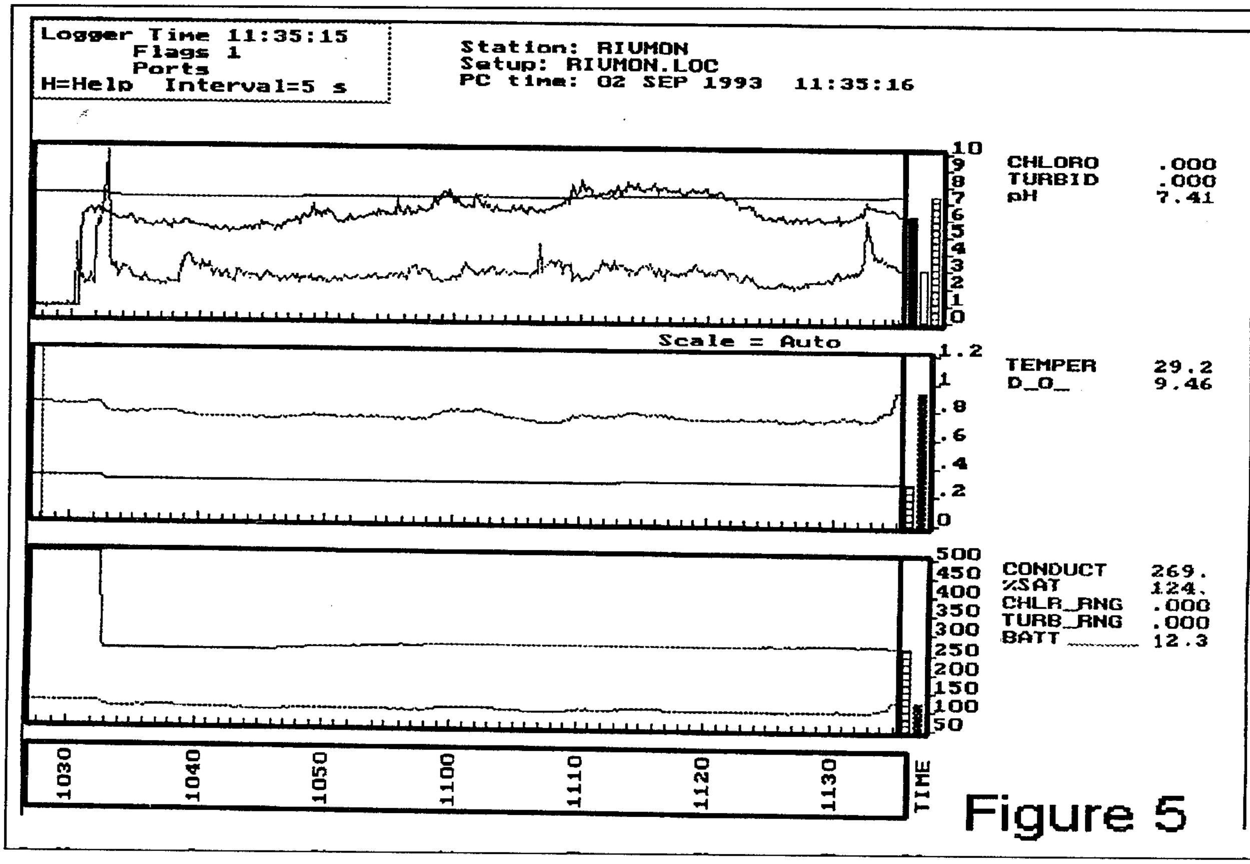


*Figure 5. Screen-captured graphic of data as it is plotted*

Schedules are to be made in conjunction with times of satellite overflights, and sampling hopefully can be conducted for several years at both normal and low flows.

If possible, the efforts will be interagency in nature and involve Huntington District, the Ohio River Valley Water Sanitation Commission, and the State environmental agencies of West Virginia and Kentucky.

River data, collected in conjunction with satellite remote sensing, can be used to establish a "truthed" database that can be used during periods of critical low flows to provide a synoptic view of riverine water quality conditions. Remote sensing, together with limited field collections, would be used for real-time evaluation of water quality in the Huntington District reach of the Ohio River and major tributaries.

# Effects of the Tioga-Hammond Lakes Project on the Water Quality of the Tioga River as Measured by Changes in Aquatic Biota

*by*
*Kenneth P. Kulp*[1] *and Dawn M. Pisarski*[1]

## Introduction

The Tioga River in north-central Pennsylvania has been severely degraded by acid mine drainage for over 100 years. The Tioga-Hammond Lakes Project, consisting of two lakes constructed by the U.S. Army Corps of Engineers in the late 1970s, has improved the water quality of the river. Prior to the construction of the flood control project, aquatic life in the river was extremely limited by acid mine pollution. Biological investigations conducted from 1980 to present show that the Tioga River now supports a much more diverse population of aquatic organisms, indicative of improved water quality. The improvement has occurred both in the impounded reach of the Tioga River and in the reach downstream from the project. The purpose of this report is to describe the biological investigations and interpret the results generated thus far relative to water-quality conditions.

## Description of the Study Area

The Tioga-Hammond Project is located in Tioga County in north-central Pennsylvania, approximately 25 miles south of Corning, NY, and 8 miles north of Mansfield, PA (Figure 1). The Tioga River originates on Armenia Mountain in Bradford County, Pennsylvania, and flows in a southwesterly direction into Tioga County. Near Blossburg, the river turns and flows approximately north until it joins with the Cohocton River near Corning, NY, forming the Chemung River, which drains to the Susquehanna River. The total length of the river is about 58 miles, and it has a drainage area of 1,391 square miles. The primary tributaries to the Tioga River are the Canisteo and Cowanesque rivers, and Mill, Cory, and Crooked creeks.

The study area lies within the Allegheny Plateau physiographic province, with broad valleys and steep, rounded hills. Relatively insoluble shale, sandstone, and bituminous coal are the primary rock types underlying the area. The coal deposits, which are extensively deep and have been strip mined, are confined to the southeastern portion of the basin in the vicinity of Blossburg. Mining activities in the area began in the 1800s and reached peak productions in 1886 (U.S. Army Corps of Engineers 1977). Strip mining continued in this area until 1983, and many of the old mines remain unreclaimed. Other than the areas disturbed by mining in the vicinity of Blossburg, the land in the basin is primarily forested or in agricultural uses. It is predominantly a rural area, with most of the population centered in several small towns and villages.

## Description of the Tioga-Hammond Lakes Project

The Tioga-Hammond Lakes Project was completed in 1978, and the lakes were filled in 1981. The primary purpose of the Tioga-Hammond project is flood protection to downstream areas, and the secondary purposes are recreation and downstream water quality enhancement. The project is located near the

[1] U.S. Army Engineer District, Baltimore; Baltimore, MD.

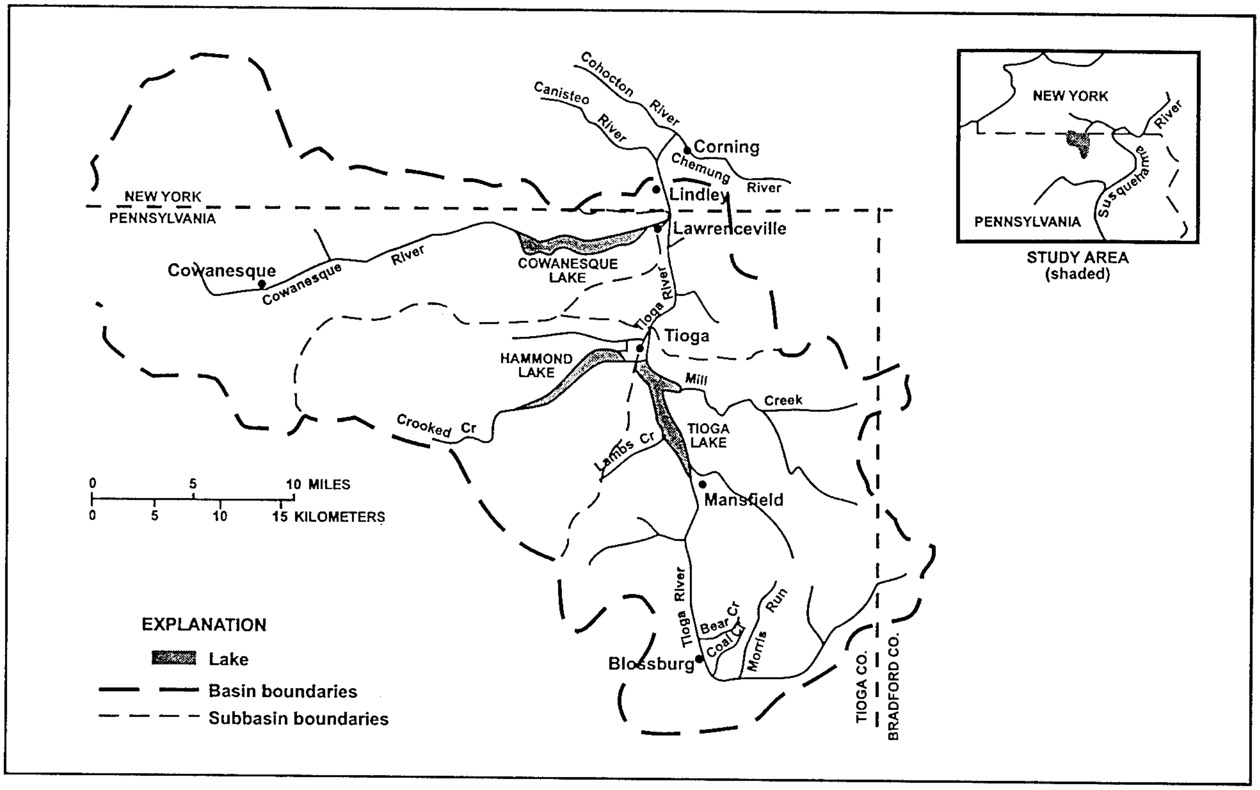


*Figure 1. The Tioga River basin*

town of Tioga and consists of two man-made lakes, Tioga Lake and Hammond Lake, that are connected by a 2,700-ft long channel cut between the drainage divide near the downstream end of the lakes. Tioga Lake impounds the Tioga River and controls a drainage area of 280 square miles. At a normal pool elevation of 1,081 ft National Geodetic Vertical Datum (NVGD), the pool has a surface area of 470 acres and stores 9,500 acre-ft of water. Hammond Lake impounds Crooked Creek, controlling 122 square miles of drainage. At the normal pool elevation of 1,086 ft NGVD, Hammond Lake has a surface area of 680 acres and contains 8,850 acre-ft of water (U.S. Army Corps of Engineers 1988).

The connecting channel between the lakes allows them to share a flood control outlet structure, located on Tioga Lake, and an emergency spillway, located on Hammond Lake. A weir in the connecting channel separates the water in the two lakes. During normal conditions, discharges from Hammond Lake are made through the weir into Tioga Lake and through a small capacity outlet in the Hammond Dam to maintain flows in Crooked Creek. Flow from Hammond Lake into Tioga Lake is controlled by a gate structure in the weir. During flood conditions, the levels of the lakes can rise above the weir (elevation 1,101 ft NGVD), becoming a single lake that is managed by the Tioga outlet works or the Hammond emergency spillway.

The Tioga outlet works contains two flood gates and two low flow gates with four intake portals. The intake portals are located at different elevations to allow for selective withdrawal from the lake for water quality control purposes.

## Biological Investigations

The Baltimore District of the U.S. Army Corps of Engineers has conducted annual biological investigations at selected lake and stream sites in the Tioga River basin since 1982. Prior to 1982, the District also supported biological studies in the basin in 1970

(Barker 1971) before project construction, and in 1980 (Water Quality Section, U.S. Army Corps of Engineers 1981) after project construction, but before complete filling of the lakes. The studies have focused primarily on fish and benthic macroinvertebrate populations, with some data being collected on plankton and aquatic vegetation. Over the years, the conduct of the studies has been dynamic, with various sampling methods and techniques being used. For the most part, the data have been qualitative; however, some quantitative data have been collected, particularly since 1991. The studies in general consisted of the collection, identification, and enumeration of a representative sample of the fish and benthic macroinvertebrate communities at each of the selected sampling locations.

The purpose of these investigations is to enhance the chemical and physical water quality studies being conducted in the basin and to provide an additional means of evaluating the water quality impacts of the project. One of the major strengths of using biological data to evaluate water quality impacts is that the aquatic organisms are continuously exposed to their environment and will react to changes within it. Episodic changes in water quality that might be missed by routine chemical and physical data collection programs will usually be reflected in the biological community if they are environmentally significant. The U.S. Environmental Protection Agency (Plafkin et al. 1989) reported the following advantages of using biological communities to assess water quality:

*a.* Biological communities reflect the overall ecological integrity (chemical, physical, and biological) of a water body; thus the results directly assess its status relative to the primary goal of the Clean Water Act.

*b.* Biological communities integrate the effects of different pollutants and stresses and thus provide a measure of their combined impact.

*c.* The status or "health" of the biological community is of interest to the general public and is better understood as a means of measuring environmental change, as opposed to chemical and physical water quality data.

*d.* Routine biological monitoring can be relatively inexpensive when compared with detailed chemical and physical data collection programs and toxicity testing.

Certain characteristics of fish and benthic macroinvertebrate communities make them particularly useful groups of organisms to study relative to water quality assessments. In the case of fish, the fact that they are relatively long lived (several years) and mobile makes them good indicators of long-term conditions within a fairly large area. Fish are also fairly easy to collect and identify, and the environmental requirements of many species of fish are well known. Benthic macroinvertebrates usually have a life cycle of approximately 1 year and have limited mobility in comparison to fish. For these reasons, they reflect short-term environmental variation and localized conditions. These organisms are also easy to collect and identify, and considerable information exists on their tolerance levels to various environmental conditions. As such, the presence or absence of certain types of fish and/or macroinvertebrates is indicative of a range of environmental conditions that must have existed in order to support the organisms.

In addition to the information provided by the presence or absence of certain "indicator" organisms, the richness, abundance, and diversity of the fish and macroinvertebrate community also provide insights into the water-quality conditions that exist at a site. In general, a healthy biological community indicative of good water quality consists of a relatively large number of types of organisms, in which no one type is considerably more abundant. In stressed aquatic communities,

the less tolerant organisms will decrease in number, while the more tolerant forms will increase. Thus the richness (number of types) and diversity of the community will decrease. The diversity is usually measured by a diversity index, which is a function based on the number of different types of organisms (richness) and the relative numbers of each type (abundance).

## Water Quality in the Tioga River

The water quality of the Tioga River has been degraded by acid mine drainage containing sulfuric acid, iron, and other metals for over 100 years. Prior to the construction of the Tioga-Hammond Project, the effects of this pollution were noted as far downstream as Corning, NY (Ward 1981). Water quality improved with distance downstream from the sources of acid mine drainage primarily because of dilution by unpolluted tributaries. Because the pollution load remains relatively constant, water quality is also dependent on streamflow conditions. During periods of high flow, the water quality improves because of dilution by runoff. During low-flow conditions, the water quality decreases because mine polluted groundwater contributes a high percentage of the flow. This relationship can be seen in Figure 2, where pH, specific conductance, and streamflow have been plotted for a typical period of time.

Water quality in the river has improved since the construction of the Tioga-Hammond Project. These improvements are predominantly a result of the project; however, some changes have also been caused by mine reclamation projects that have reduced the pollution loading to the river. There are several methods by which the project improves water quality. These include mixing, dilution, and selective withdrawal. Alkaline water from Hammond Lake is mixed with the acidic waters in Tioga Lake by releases through the connecting channel. This buffers the water

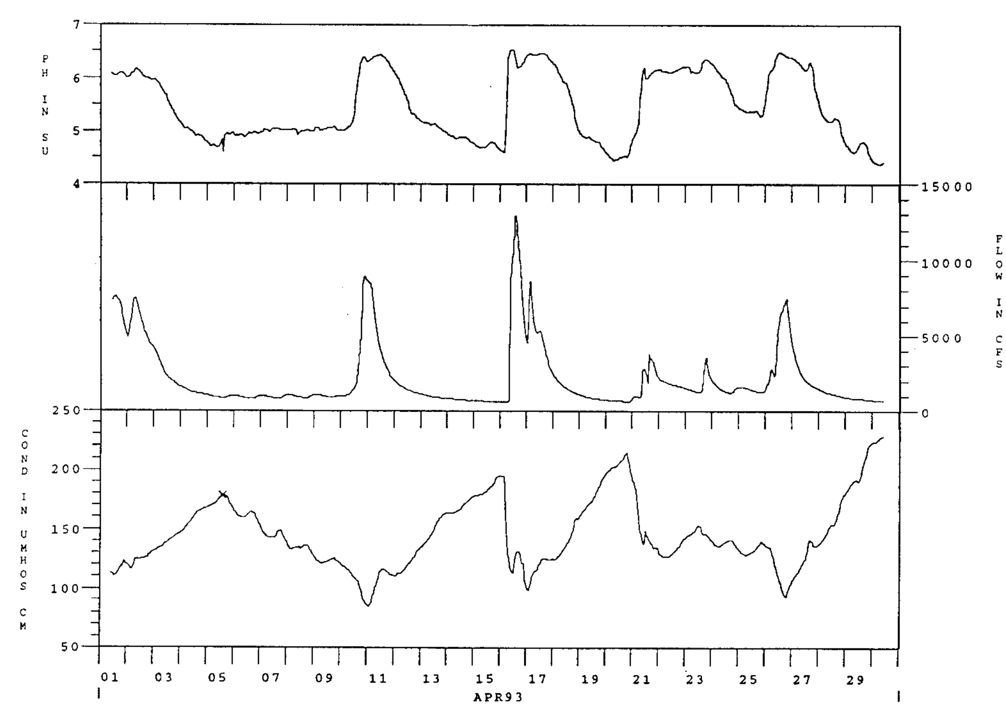


*Figure 2. Typical relationship between streamflow and water quality in the Tioga River near Mansfield, PA*

and raises the pH. High-quality water from Mill Creek also flows into the lake and has a similar influence. During periods of low flow when inflow water quality is normally poor, the water is stored in the lake until it is diluted with better quality inflow water or mixed and buffered with water from Hammond Lake and Mill Creek. Because Tioga Lake is frequently stratified, with water of different quality at different depths, selective withdrawal through the multilevel water quality portals in the outlet works is used to improve the quality of releases and the lake water. Complex flow patterns in Tioga Lake, particularly in the winter during periods of ice cover, complicate water quality control. After several years of investigation and testing various operational methods in the early to mid-1980s, water quality control operations that are successful under most conditions were developed in 1986. No known fish kills have occurred in the lake or downstream since these control operations were implemented.

A summary of pH and specific conductance data for selected reaches of the river before and after project completion is shown in Table 1. A comparison summary of biological data is shown in Figures 3 and 4. A more detailed discussion of preproject and postproject water quality conditions in selected reaches of the river follows.

## Preproject Conditions

The 12-mile reach of the river from its headwaters to the confluence of Morris Run had excellent water quality, as evidenced by relatively neutral pH values and low specific conductance (see Table 1). This upstream reach of the river supported a trout fishery and a diverse population of aquatic organisms indicative of clean water (Barker 1971).

From the confluence of Morris Run to Mansfield (about 10 miles), the water quality of the river was severely degraded by acid mine drainage. Both strip mines and deep mines produced the pollution, which traveled from the mines to streams in the area mostly by way of groundwater flow. The primary

**Table 1**
**pH and Specific Conductance in Selected Reaches of the Tioga River Before and After Construction of the Tioga-Hammond Lakes Project**

| | pH (standard units) | | | Specific Conductance (microsiemens/cm at 25 °C) | | |
|---|---|---|---|---|---|---|
| Reach | Minimum | Maximum | Median | Minimum | Maximum | Median |
| A | | | | | | |
| Before | 5.7 | 7.5 | 6.8 | 34 | 251 | 52 |
| After | 4.1 | 5.3 | 4.8 | 49 | 296 | 100 |
| B | | | | | | |
| Before | 3.0 | 5.6 | 4.2 | 118 | 780 | 460 |
| After | 3.5 | 7.2 | 5.2 | 90 | 750 | 300 |
| C | | | | | | |
| Before | 3.1 | 6.6 | 4.6 | 109 | 610 | 410 |
| After | 5.7 | 7.1 | 6.6 | 145 | 350 | 300 |
| D | | | | | | |
| Before | 4.6 | 7.8 | 6.7 | 102 | 364 | 260 |
| After | 6.4 | 7.8 | 7.0 | 75 | 300 | 210 |
| E | | | | | | |
| Before | 6.1 | 8.4 | 7.2 | 118 | 359 | 300 |
| After | 6.5 | 8.0 | 7.2 | 120 | 350 | 290 |

Note:
Reach A = Headwaters to confluence of Morris Run.
Reach B = Morris Run to Mansfield.
Reach C = Mansfield to confluence Crooked Creek.
Reach D = Crooked Creek to confluence of Cowanesque River.
Reach E = Cowanesque River to confluence of Canisteo River.
Before data from Barker (1971) and Ward (1981). After data from unpublished U.S. Army Corps of Engineers data for 1990-93 except Reach A, which is based on 1982-83 data.

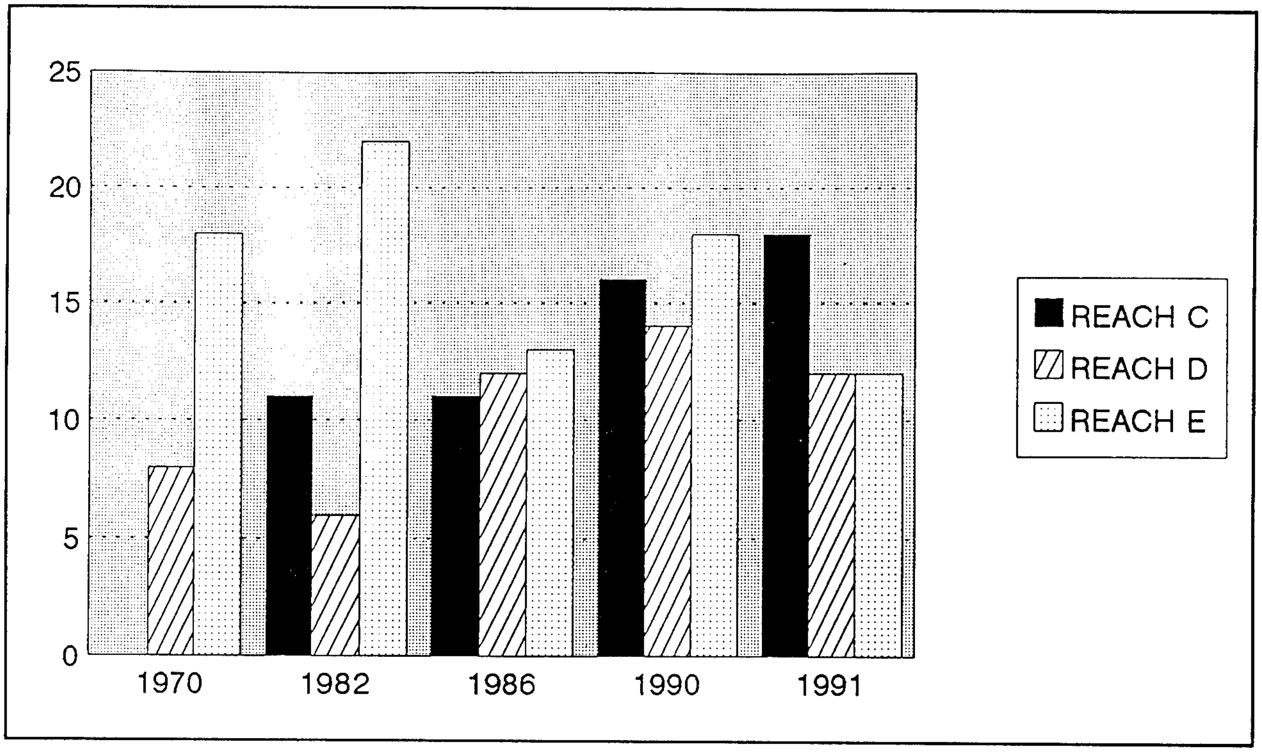


*Figure 3. Number of fish species found in selected reaches of the Tioga River*

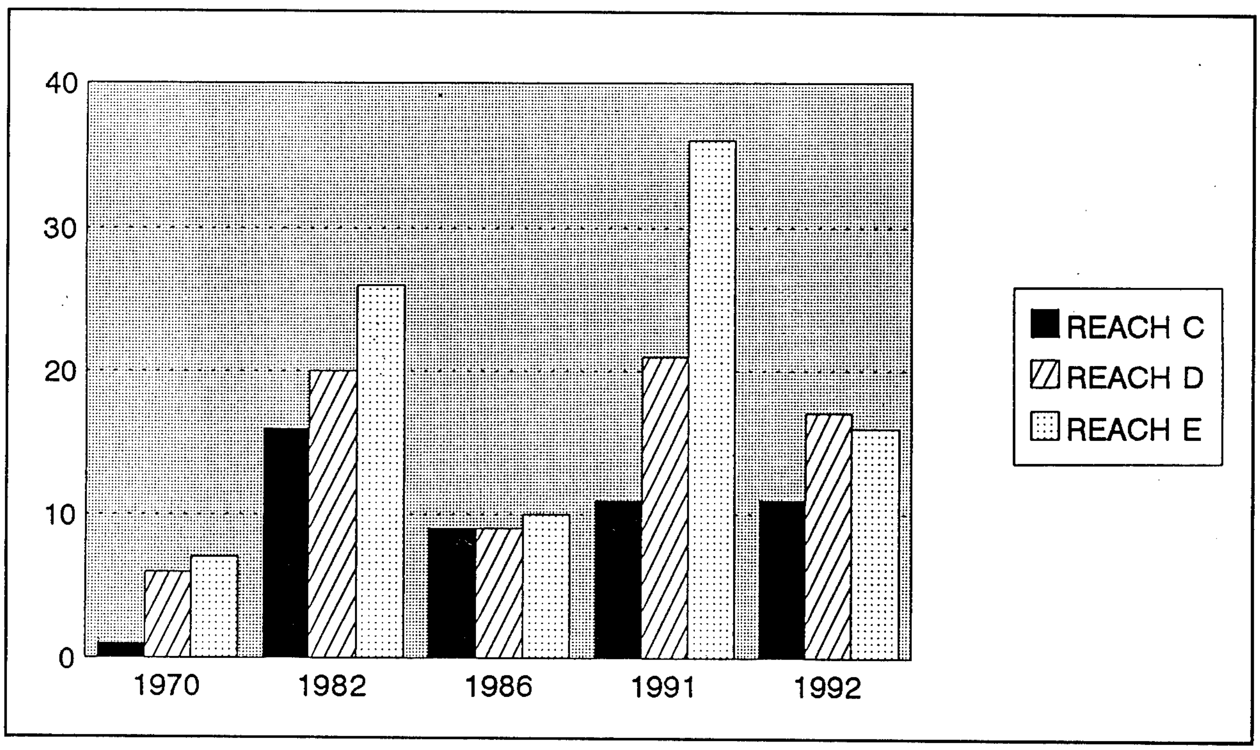


*Figure 4. Number of macroinvertebrate species found in selected reaches of the Tioga River*

tributaries carrying the pollution to the river were Morris Run, Coal Creek, and Bear Creek, which join with the Tioga River in the vicinity of Blossburg. The most obvious impact of the pollution was the decrease in pH that occurred as a result of the sulfuric acid in the mine drainage. Data from the 1970s (Barker 1970; Ward 1981) show that the pH in this reach of the river dropped as low as 3.0 and was normally about 4.2. The specific conductance was high, and precipitation of iron coated the bottom with yellow-boy (ferric hydroxide). Although several species of algae that are tolerant of low pH and high iron and sulfate concentration were present in this reach, no fish or macroinvertebrates were found in 1970 (Barker 1970).

The water quality in the 8.5-mile reach of the river between Mansfield and the confluence of Crooked Creek prior to impoundment was poor, although some improvement in water quality occurred as a result of dilution with water entering from Mill Creek and several smaller tributaries. The pH was normally about 4.6, with values of 3.3 during low-flow periods. Specific conductance was relatively high, and yellow-boy continued to coat the streambed, although not as heavily as in the reach above. Where Mill Creek enters the river, Barker (1970) noted that the yellow-boy was replaced with aluminum hydroxide. Algae and some rooted aquatic vegetation were present in this reach, but only one macroinvertebrate (a midge larvae) was found in 1970. Fish were not found in this reach of the river. The lack of animal life is indicative of the extremely poor water quality that existed in this reach.

Downstream from the confluence of Crooked Creek to the confluence of the Cowanesque River (about 8.5 miles) was a zone of intermittent recovery. This recover was due to the inflow of Crooked Creek, which has water of relatively good quality. According to Ward (1981), the pH values of Crooked Creek at the confluence with the Tioga River were usually 7.4 to 7.9, with an alkalinity of 41 to 54 mg/L as calcium carbonate. As a result of the buffering provided by this inflow, water quality in this reach normally ranged from fair to good; but during low flow, acidity continued to be a problem. Barker (1970) reported that pH ranged from 4.6 to 7.8, and the stream bottom was colored gray by aluminum hydroxide. He found algae and rooted aquatic vegetation to be present, along with eight species of fish and six types of macroinvertebrates. The presence of these organisms shows that water quality had improved considerably from conditions upstream, but the lack of "richness" and intolerant organisms in the populations were still indicative of impaired water quality. The macroinvertebrate community was comprised primarily of acid-tolerant organisms, including caddis fly larvae of the family Hydropsychidae, Chironomid midge larvae, and fishfly larvae (*Sialis*).

The final 8.7-mile reach of the Tioga River included in this investigation, from the confluence of the Cowanesque River to the confluence of the Canisteo River, continued to show recovery from the acid mine pollution. Again, the cause of the recovery was predominantly due to dilution. In this case, the alkaline water of the Cowanesque River (median pH 7.8, alkalinity 48 mg/L as $CaCO_3$) effectively buffered the remaining acidity in the Tioga River under most conditions. The pH of the river in this reach was reported to range from 6.1 to 8.4, with a median of 7.2 (Ward 1981). A slight gray-blue coloration because of aluminum hydroxide was still evident on the streambed. The biota in this reach included 18 species of fish, a significant increase from the previous reach, and 7 types of macroinvertebrates. Although the macroinvertebrate community showed only a slight increase in richness (7 types versus 6 types at above reach), it included several "clean-water" types such as mayflies, caddis flies, dobson flies, and riffle beetles (Barker 1970). Overall, the biotic community in this reach was indicative of relatively good water quality existing most of the time, with limited and infrequent stress from acid mine pollution.

## Postproject Conditions

Little recent data exist to evaluate water quality in the uppermost reach of the river after the construction of the project; however, data collected in 1982 and 1983 indicate that some degradation took place in the form of acidification. Samples collected during this period showed that the pH ranged from 4.1 to 5.3, which is considerably lower than the range reported previously. The cause of the apparent acidification is not known, but it may have been related to mining activity somewhere in the headwaters. More recent data for this reach of the river was not found, so its present condition is unknown.

The reach of the river between the confluence of Morris Run and Mansfield continues to be severely degraded by acid mine pollution, but some improvement has occurred. The improvement is probably due to mine reclamation projects that have taken place in the vicinity of Blossburg. The pH in this reach is now normally about 5.2, in contrast to the preproject normal of 4.2. Unfortunately, during periods of low flow, the pH seldom exceeds 4.5, and drops as low as 3.5. The streambed continues to be covered with yellow-boy, and there are still no fish or benthic macroinvertebrates in this reach.

Most of the third reach of the river, extending from Mansfield to the confluence of Crooked Creek, is now part of Tioga Lake. Water quality in this reach has improved considerably, as evidenced by both chemical and biological data. Although it is still affected by periodic slugs of acidic water, water-control operations have usually been able to maintain a pH of between 5.7 and 6.8 in the lake and area immediately downstream. Yellow-boy no longer coats the bottom, but some aluminum hydroxide precipitate is evident in the upper portion of this reach. The biological community now present in this reach of the river indicates the greatest overall improvement of any reach under investigation. This improvement was first noted in 1982, when the first biological investigation was conducted following completion and filling of the lakes. While previous investigations had found no fish in this reach, 11 species were found in 1982. In the most recent investigation in which data on fish populations were collected, 1991, the fish community was comprised of 18 species of fish. The composition of the fish community is fairly diverse, including game fish, rough fish, and forage fish, indicative of reasonably good water quality. The benthic macroinvertebrate community shows similar improvement. In 1982, 16 types of macroinvertebrates were found, including clean-water forms such as mayflies and caddisflies. By comparison, no macroinvertebrates were found in this reach in 1970, and only two were found in 1980 prior to the lakes being filled. Evidence of some acid stress was evident in 1982, however, as 75 percent of the population was comprised of caddis flies in the family *Hydropsychidae*, which are relatively acid tolerant. The diversity index for this sample also reflects some stress, as it is only 1.35. Current conditions, as reflected by the 1992 macroinvertebrate sample, show continued improvement. Although fewer types were present (11), the population was more evenly distributed, and the acid-tolerant *Hydropsychidae* comprised only 50 percent of the population. The diversity index for this sample was 2.48, indicative of fairly good water quality. Overall, the biological data indicate that water quality in this reach now ranges from fair to good, with some acid-stressed periods. These periods of stress are considerably less severe than those experienced during preproject conditions.

A noticeable improvement in water quality has also occurred in the Tioga River between the confluence of Crooked Creek and the confluence of the Cowanesque River. The minimum pH in this reach is now about 6.4, compared with values as low as 4.6 during preproject conditions. Under normal flow conditions, the pH is about neutral, 7.0. Yellow-boy and aluminum hydroxide precipitate are no longer evident on the streambed, indicative of a decrease in the acid mine pollution reaching this stretch of river. The biological

community also shows a decrease in stress. In 1982, the number of fish species climbed to 11 from the 8 reported previous to the project, and the number of macroinvertebrate types increased from 6 to 20. The macroinvertebrate community included mayfly, stonefly, and caddis fly larvae, indicative of good quality water. Acid-tolerant types comprised about 50 percent of the population compared with approximately 75 percent in 1970. The 1991 and 1992 biological data are similar to the 1982 data, indicating no significant change in the water quality following the initial improvement noted shortly after project completion and filling. Twelve species of fish and 21 types of macroinvertebrates were found in 1991, and 17 types of macroinvertebrates were found in 1992, when no fish data were collected. The relatively rich and diverse biota (diversity index 1991 = 3.25, 1992 = 2.86) now present in this reach are indicative of good water quality.

The final reach of the river between the confluence of the Cowanesque and Canisteo rivers has shown minor improvement since completion of the Tioga-Hammond Project. The minimum pH in this reach is now 6.5, and aluminum hydroxide precipitate is no longer present. No significant impacts of acid mine pollution are seen in this reach. The biological community is indicative of consistently good water quality. In 1982, 22 species of fish were found in this reach, and in 1990, 18 species were found. In 1991, only 12 species were collected, but this apparent decline may be related to collection procedures. Personal observation in 1991 indicated that the equipment used to collect fish was inadequate for the width and depth of this reach. Macroinvertebrate data show that the number of types increased from 7 in 1970 to 26 in 1982. In 1991, there were 36 types of macroinvertebrates present, indicative of excellent water quality; in 1992, there were 16 types present, still indicative of good quality.

## Conclusions

Biological data collected from selected reaches of the Tioga River indicate that the water quality has improved since the completion of the Tioga-Hammond Project. This improvement is also reflected by chemical and physical data. The cause of the improvement is primarily due to water quality operations at the project, although some improvement may also be related to decreased acid mine pollution in upstream reaches resulting from mine reclamation. The most significant improvement has taken place in the reach now impounded by Tioga Lake and in the reach downstream of the lake to the confluence of the Cowanesque River. The presence of a relatively rich and diverse community of aquatic organisms in these reaches, which previously supported only a limited number of acid-tolerant organisms, is indicative of a substantial decrease in the severity of episodic acid slugs that previously degraded it.

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# Gas Supersaturation at Jennings Randolph Lake

*by*
*Kenneth S. Lee*[1]

## Introduction

Gas supersaturation has been identified as a potential environmental problem associated with releases from Corps projects in the Columbia River basin and the Missouri River basin since the 1960s and 1970s. In the early 1980s, Corps field offices were directed to evaluate gas supersaturation at their projects in accordance with the guidelines outlined in ETL 1110-2-239, subject: Nitrogen Supersaturation, dated 15 September 1978. The Baltimore District evaluated the potential of gas supersaturation at all of its projects and concluded that no problems were anticipated.

An unexpected event occurred in the tailwater of the Jennings Randolph Lake project in late May 1990. Severe fish kills were observed in the fish-rearing pens within the stilling basin even though the project was discharging only 4,200 cfs. First, it was assumed that chemical toxicity, especially aluminum and pH, had caused the problem, but later it was found that gas supersaturation had caused the fish kill.

This paper describes the gas supersaturation problem at Jennings Randolph lake and discusses alternative measures for prevention.

## Background

Jennings Randolph Lake is located on the boundary between Garrett County, Maryland, and Mineral County, West Virginia, on the North Branch Potomac River. The project was authorized by the Flood Control Act of October 1962 under the name of Bloomington Lake. Its purposes are to provide water quality control in the North Branch Potomac River, industrial and municipal water supply for the Potomac River basin, flood control protection for the North Branch communities, and recreation associated with the lake, downstream, and surrounding facilities. The construction of the project was completed in 1981.

Water quality in Jennings Randolph lake is poor to fair. Acid mine drainage (AMD) in the watershed degrades pH. The pH in the reservoir typically ranged from 5.5 to 6.7 during the early 1980s. Recently, the pH has improved somewhat (6.1 to 6.9), and tailrace water quality has become fair to good. The nutrient loading in reservoir is moderate for nitrogen and very low for phosphate. During the planning stage, no fish were expected in the reservoir; however, a few fish have been observed in the lake and tailwater in recent years.

The Maryland Department of Natural Resources initiated a fish-rearing operation in net pens installed in the stilling basin during August 1989. Floating devices were installed along the left wing wall. Ten net pens made of nylon and sized 20 by 15 by 10 ft were installed on the floating devices. Currently, 80,000 to 150,000 trout ranging from yearling to adult size are being raised, and their growth rate is excellent (1 in. per month).

It has been observed that fish mortality rate at Jennings Randolph Lake increases with an increase in outflow rate. This mortality increase is associated with gas supersaturation and is related to gas bubble diseases, which occur when fish are exposed to prolonged periods of water containing supersaturated gases. Major external symptoms of gas bubble diseases are exopthalmia or pop-eye, bubbles in the caudal

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fin, hemorrhage, and emboli in gill blood vessels.

## Basic Process of Gas Supersaturation

The cause of gas supersaturation is air entrainment within a water jet that plunges into a significant depth of water. The entrained air is transported as bubbles to the bottom of the stilling basin. The bubbles become dissolved in the water under hydraulic pressure; the result is gas supersaturation in the released water. The magnitude of gas supersaturation depends upon the type of hydrostatic structures, magnitude of discharge, and depth of water in the stilling basin.

The saturation rate in the stilling basin differs with water depth. Hydrostatic pressure increases with water depth, and the saturation rate decreases with greater hydrostatic pressure. The saturation level reaches its highest level on the surface because of minimal hydrostatic pressure and reaches its lowest level on the bottom because of maximum hydraulic pressure.

Figure 1 illustrates the relationship between gas supersaturation versus outflow measured 1 ft deep from the surface in the stilling basin. Gas supersaturation reaches 110 percent with discharge of 1,500 cfs and 117 percent with 2,500 cfs. When outflow exceeds 3,500 cfs, the saturation reaches around 120 percent according to graph.

Gas bubble diseases occur when fish are exposed to saturation levels of 110 percent or above. Degrees of gas bubble diseases in fish depend upon duration and saturation level. Fishery biologists from the Maryland Department of Natural Resources have observed that trout exposed to saturation levels of 115 percent for a few hours have experienced minor distress; and severe distress and mortality occur when fish are exposed to saturation levels greater than 120 percent for the same period.

The rearing fish nets drift upward with an increase in the discharge rate. Fish in the rearing pens, therefore, have more exposure to higher saturation levels when discharge rates are increased.

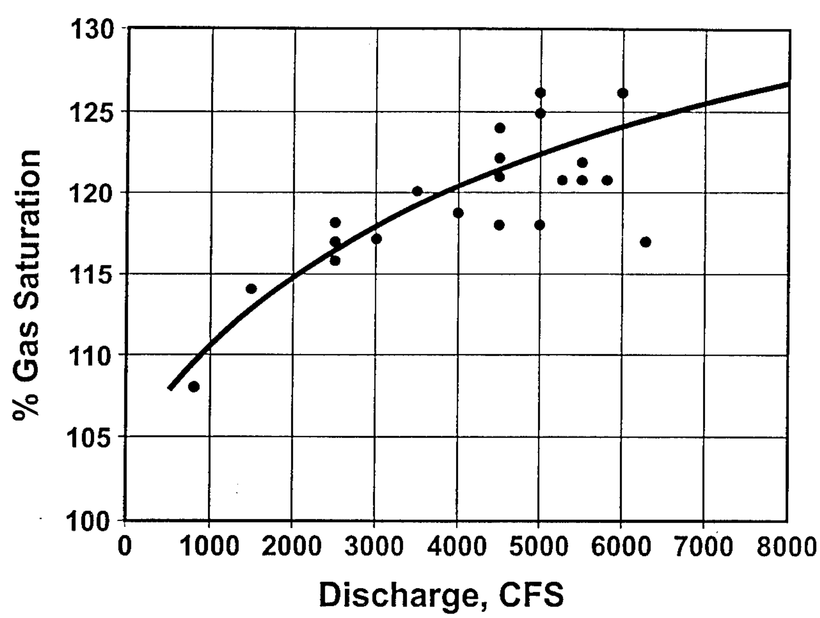


*Figure 1. Relationship between gas supersaturation and outflow rate*

Most of the time, the operation plan for Jennings Randolph Lake limits the outflow to 1,500 cfs or less. However, outflows sometimes exceed 2,500 cfs in the spring and summer.

## Mitigation for Gas Supersaturation

Methods for mitigation of gas supersaturation are categorized as follow: (a) operational modifications to reduce its magnitude and frequency, (b) structural measures to prevent its formation, and (c) remediation after supersaturation has occurred.

### Operational modifications

Operational modifications for minimizing gas supersaturation levels include controlling the discharge rate and the frequency of high volume discharges. A reservoir operational plan, which is a reservoir guide curve, is a major tool. The Jennings Randolph Lake project does not have a strict reservoir guide curve. Typically, the project has been operated to obtain maximum benefits for water quality in the lake and downstream utilizing 51,000 acre-ft of water quality storage. The pool fluctuates storing large inflows for later release to augment flows by 200 to 500 cfs at downstream control points for water quality purposes.

The pool is generally maintained around the full conservation pool (elev 1,466 ft) during the April through June period. The pool sometimes drops 20 to 60 ft below the conservation pool during other times of the year. Figure 2 shows a plot of typical pool elevation versus time in Jennings Randolph Lake.

A vacant storage approach is one of the operational modification methods frequently used in the spring and summer. This method evacuates the 3,000 to 4,000 acre-ft of storage from the conservation pool in advance when inflow is expected to be high in order to reduce the discharge rate and its frequency .

Another operational modification method is temporary use of flood control storage. Under this method, the flood control storage of 2,000 to 3,000 acre-ft is used for a short

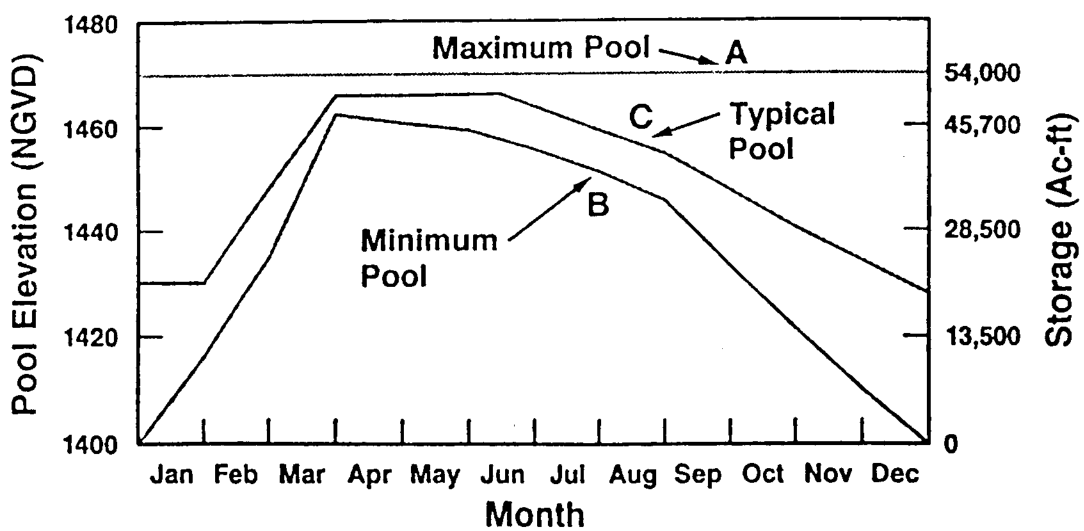


*Figure 2. Operating ranges of pool elevation for water quality operations, Jennings Randolph Lake*

period to store minor rapid rises in inflow, gradually released afterwards.

## Structural measures

Structural measures for controlling gas supersaturation include modifying structures to prevent the plunging of air-entrained flow into the stilling basin and keeping fish in deeper water. Methods for preventing plunging are installing a flip bucket on the stilling basin trajectory and lowering the tailrace water level.

The flip bucket (Figure 3) would deflect the flow across the surface of the tailwater rather than allowing it to plunge deep into the stilling basin. Its effectiveness is somewhat dependent upon the discharge rate. The deflector becomes ineffective if it is inundated. The flip bucket should be designed to effectively handle the maximum discharge capacity (16,500 cfs) from the tunnel.

The existing stilling basin, however, has a performance problem unrelated to gas supersaturation. When outflows exceed 7,000 cfs, an unstable flow condition is created in the tunnel. As a result, rough waves of 4 to 6 ft high are created in the stilling basin. When the outflow exceeds 9,000 cfs, riprap by the wing walls are washed out. Under these conditions, installing the flip bucket for control of gas supersaturation would probably make the stilling basin performance worse.

Lowering the tailrace water level would reduce gas supersaturation by reducing the depth of the plunging to water. The computations for stilling basin design were checked, based on the guideline from EM 1110-2-1602 (15 Oct 80). Figure 4 illustrates the stilling basin profile and Table 1 shows the computations for tailwater elevation versus hydraulic jump elevation. Lowering of the tailwater level between d2 and 0.85d2 might significantly reduce the gas saturation level without a problem of stilling basin performance. The existing tailrace water levels are 8.8 ft deeper at the discharge rates of 12,000 cfs and 19.6 ft at 5,250 cfs than the maximum required for acceptable stilling basin performance. Creating the proper tailwater levels for various discharge

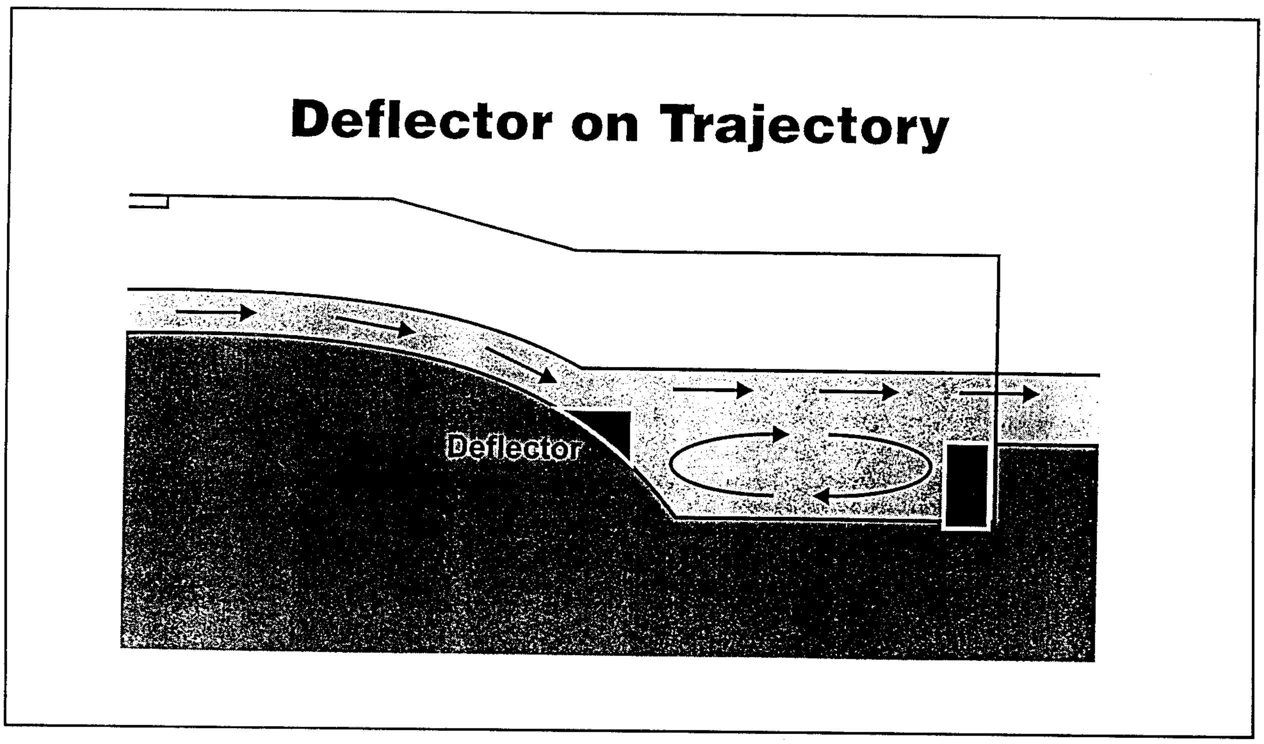


*Figure 3. Concept of flip bucket*

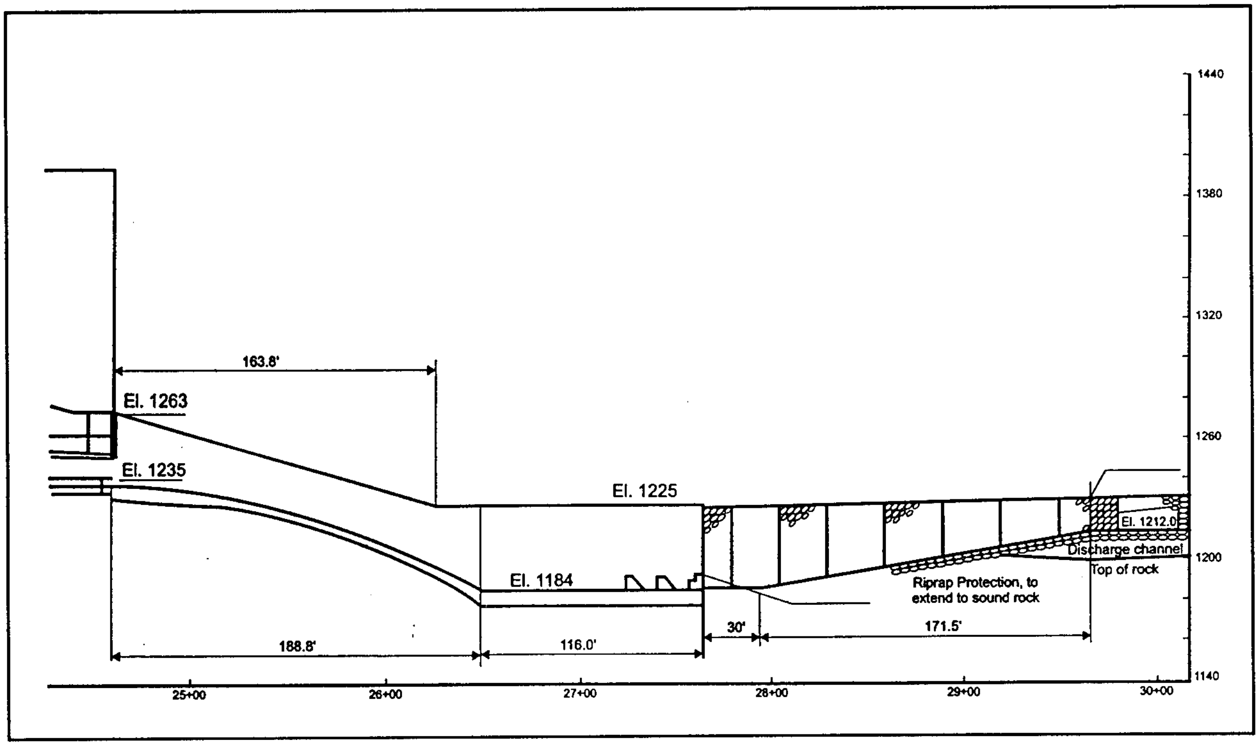


*Figure 4. Stilling basin profile*

**Table 1**
**Computations for Tailwater Elevation Versus Hydraulic Jump Elevations**

| Q [cfs] | Apron Elev. [ft] | Y [ft] | X [ft] | Wb [ft] | V1 [fps] | d1 [ft] | F1 | d2 [ft] | 0.85D2 [ft] | T.W. Elev. [ft] | Difference [ft] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 18000 | 1184 | -52.27 | 90.99 | 64 | 79.6 | 3.53 | 7.5 | 37.20 | 31.62 | | |
| | | | | | | | | 1221.20 | 1215.62 | 1225.00 | 3.80 |
| 12000 | 1184 | -52.27 | 90.99 | 64 | 74.4 | 2.52 | 8.2 | 29.40 | 24.99 | | |
| | | | | | | | | 1213.40 | 1208.99 | 1222.20 | 8.80 |
| 8000 | 1184 | -51.27 | 90.99 | 64 | 70.3 | 1.20 | 11.3 | 18.60 | 15.81 | | |
| | | | | | | | | 1202.60 | 1199.81 | 1220.00 | 17.40 |
| 6850 | 1184 | -51.27 | 90.99 | 64 | 69.0 | 1.04 | 11.9 | 16.98 | 14.43 | | |
| | | | | | | | | 1200.98 | 1198.43 | 1219.30 | 18.32 |
| 5250 | 1184 | -51.27 | 90.99 | 64 | 67.1 | 0.82 | 13.0 | 14.70 | 12.50 | | |
| | | | | | | | | 1198.70 | 1196.50 | 1218.30 | 19.60 |
| 3650 | 1184 | -51.27 | 90.99 | 64 | 65.0 | 0.59 | 14.9 | 12.14 | 10.32 | | |
| | | | | | | | | 1196.14 | 1194.32 | 1217.10 | 20.96 |
| 2600 | 1184 | -51.27 | 90.99 | 64 | 63.4 | 0.43 | 17.0 | 10.13 | 8.61 | | |
| | | | | | | | | 1194.13 | 1192.61 | 1216.30 | 22.17 |
| 1000 | 1184 | -51.27 | 90.99 | 64 | 60.5 | 0.17 | 25.6 | 6.06 | 5.15 | | |
| | | | | | | | | 1190.06 | 1189.15 | 1214.20 | 24.14 |

rates requires significant modifications of the outlet channel, especially shape and size of cross section. The slope of the outlet channel is steep enough so that it would not be a problem to lower the tailwater level.

The replacement of the nylon net pens with a steel net pen may also help to reduce fish mortality. The steel net would be subjected to less uplifting compared with the nylon rearing nets while large discharges are made. Fish would find a deep place on the bottom for hiding and would be able to avoid the higher saturation level.

Use of a steel wire cover in the pens for forcing fish downward is another method to reduce the adverse effects of gas supersaturation. When the steel wire cover is installed 2 ft below the surface, fish are forced to stay 2 ft below the water level. As a result, fish are exposed less to supersaturation, which is at its highest close to the surface.

### Remediation

Supersaturation can be removed from water by creating a highly turbulent aerated flow condition. This method would be effective removing supersaturation on the downstream reach of the river, but not in the stilling basin. Below the dam on the North Branch Potomac River, the river is characterized by rough beds having many boulders and a steep slope. When large discharges are made, turbulent conditions are naturally created, and gas transfer occurs along the river. The supersaturated release from the dam is reduced along the river. The saturation level at Barnum, which is located 1 mile downstream from the stilling basin, is reduced to 108 percent when the saturation level at the stilling basin is 117 percent.

## Discussion

The operational modifications are the least costly alternatives, while the structural modifications are the most complicated and costly alternatives. Every effort has been made to institute operational modifications. These methods are able to reduce the magnitude and durations of the saturation level, but the problem still remains because the project has many operational constraints in order to archive to other project purposes. Combining the operational modifications and the structural modifications may solve the problem.

The deflector is most widely used at major projects, especially in the Pacific Northwest and at the Henry S. Truman project in the Missouri River basin. Based on the present stilling basin performance, the flip bucket may create a severe problem with stilling basin performance, especially during high discharges. Consequently, the flip bucket is not recommended.

Lowering the tailrace water level would be less complicated than installing the flip bucket; however, there are two other problems. One is the disruption of the fish-rearing pen operations because the areas at fish rearing net pens may become too shallow, and the other is the adverse environmental impact associated with riverbed excavation.

Replacing a steel net pen and covering a steel wire cover is the least in cost among the structural modifications, but these methods are cumbersome for maintenance.

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# Water Quality Changes as a Result of Coldwater Releases in Lake Moomaw

*by*
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## Introduction

Lake Moomaw is the Commonwealth of Virginia's premier trout fishery reservoir where citation catches of brown and rainbow trout are common. In addition to the coldwater fishery, the reservoir also supports a self-sustaining warmwater fishery of largemouth and smallmouth bass, crappie, catfish, and yellow perch. This "two-story fishery" has attracted anglers from a large area and provides an economic boost to the surrounding area.

From April 1981 to September 1989, the reservoir released ambient stream temperatures ranging from 4.5 to 22.2 °C. This operational scheme has effectively provided for a trophy trout fishery within the reservoir while maintaining downstream low-flow augmentation water quality needs. In October 1989, release temperatures were modified in response to requests from the Commonwealth of Virginia for the establishment of a downstream coldwater fishery. This paper documents some observations made as a result of this modification.

## Study Area

Lake Moomaw and Gathright Dam are located in Alleghany and Bath counties in western Virginia about 13 miles upstream of Covington, VA. The reservoir is formed by an impoundment of the Jackson River in the upper portion of the James River Basin. The purpose of this project is for flood control, low-flow augmentation, and recreation. The surface area of Lake Moomaw is 1,025 ha (2,500 acres) with a drainage area of 89,400 ha (345 square miles). The mean depth is 15 m (49.2 ft) with a maximum depth of 45 m (147.6 ft). The watershed for the reservoir is mostly forested and lies entirely within the George Washington National Forest.

Gathright Dam is a rolled, rock-filled embankment, 78 m (257 ft) high and 357 m (1,170 ft) long with a 5.3-m (17.5-ft) diam outlet tunnel. Releases are controlled by a multiport intake tower with 10 water quality intake ports located at nine different elevations spanning 23 m (75.4 ft). Two floodgates are located at the bottom of the tower. The filling of the reservoir began in December 1979, with normal pool operation starting in April 1982.

The operation of Gathright Dam from April 1982 to October 1989 consisted of releasing water with temperatures that approximated the ambient or predam stream temperatures. This was accomplished by selecting the water quality port closest to the objective temperature. In effect, this operation allowed the retention of sufficient cold water to allow for a "two-story fishery."

At the request of the State, operations were modified in October 1989 to provide downstream release water temperatures suitable for a downstream coldwater fishery. Objective release temperatures below 15.5 °C were made to provide for the trout-stocking program initiated by the State in December 1989. Releases, made through the multiport dual wet-well intake structure, were obtained by selecting the water-quality port closest to the objective

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temperature. This method of releasing cold water was based on results from a WESTEX model study performed in 1978. This study indicated that withdrawing from the port(s) closest to the desired discharge temperature would have a higher probability of maintaining coldwater storage throughout the year than withdrawing simultaneously from the top and bottom ports. In addition, it is less likely that releases from the port(s) closest to the desired discharge temperature would contain significant iron and manganese concentrations.

In May 1991, the Department of Game and Inland Fisheries contacted the Norfolk District to request that the releases be modified to a high-low port scheme in an attempt to preserve trout habitat within the reservoir while also maintaining the downstream coldwater fishery. An analysis performed by the Commonwealth of Virginia indicated that trout habitat within the reservoir was significantly decreased by "pulling water from the thermocline."

In response to the request from the Commonwealth of Virginia, the procedure for providing downstream coldwater releases was modified on 15 June 1993 to blend water from the upper and lower water quality ports. This change from the previous operation is an interim measure not to exceed 2 years to evaluate the potential for better maintaining the in-lake coldwater fishery and to evaluate any possible adverse impacts on the Jackson River downstream coldwater fishery and the downstream water quality.

## Observations and Discussions

The results of reservoir monitoring data are presented in Figures 1 and 2. These figures display the time history of dissolved oxygen and temperature at monitoring stations (see Figure 3) M-1 and M-4 from 1983 through 1993. The upper portion of the figures represent the 21 °C contour, and the lower portion represents the 5-mg/L dissolved oxygen contour. The area above the 21 °C contour represents temperatures exceeding 21 °C, while the area below this contour represents temperatures less than 21 °C. Similarly, the area above the 5-mg/L dissolved oxygen contour represents concentrations exceeding 5 mg/L, while the area below this contour represents concentrations less than 5 mg/L.

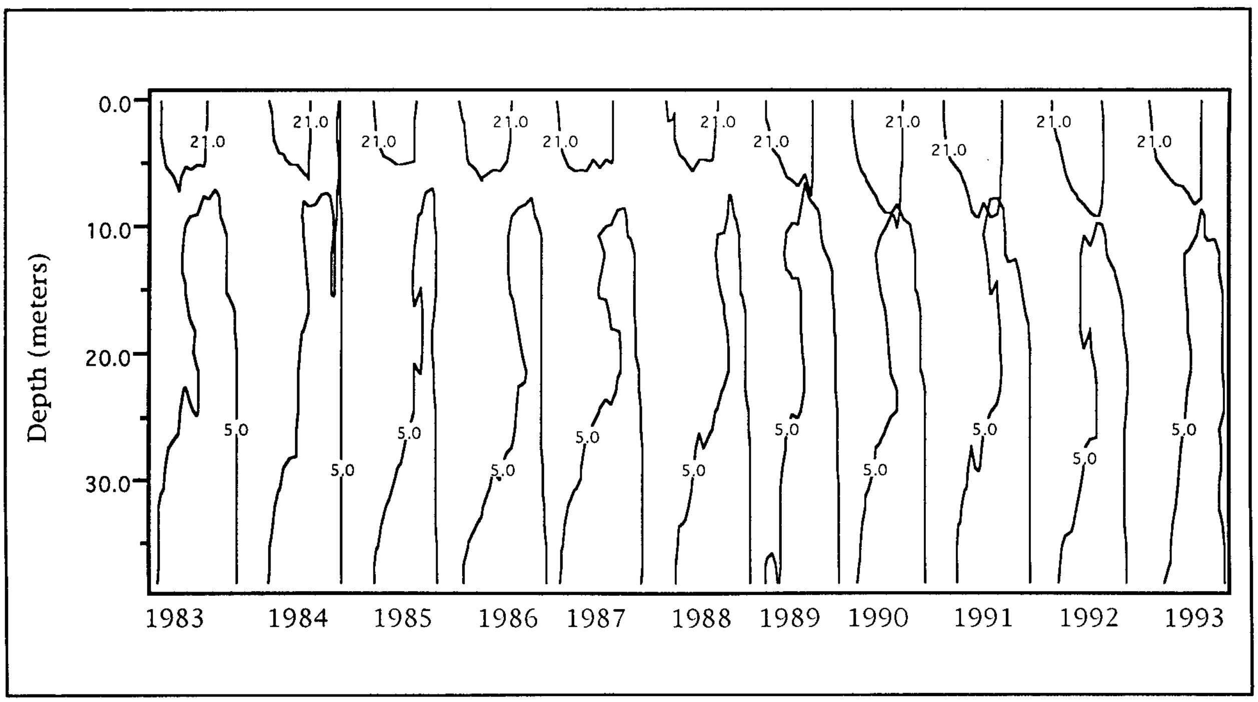


*Figure 1. Station M-1*

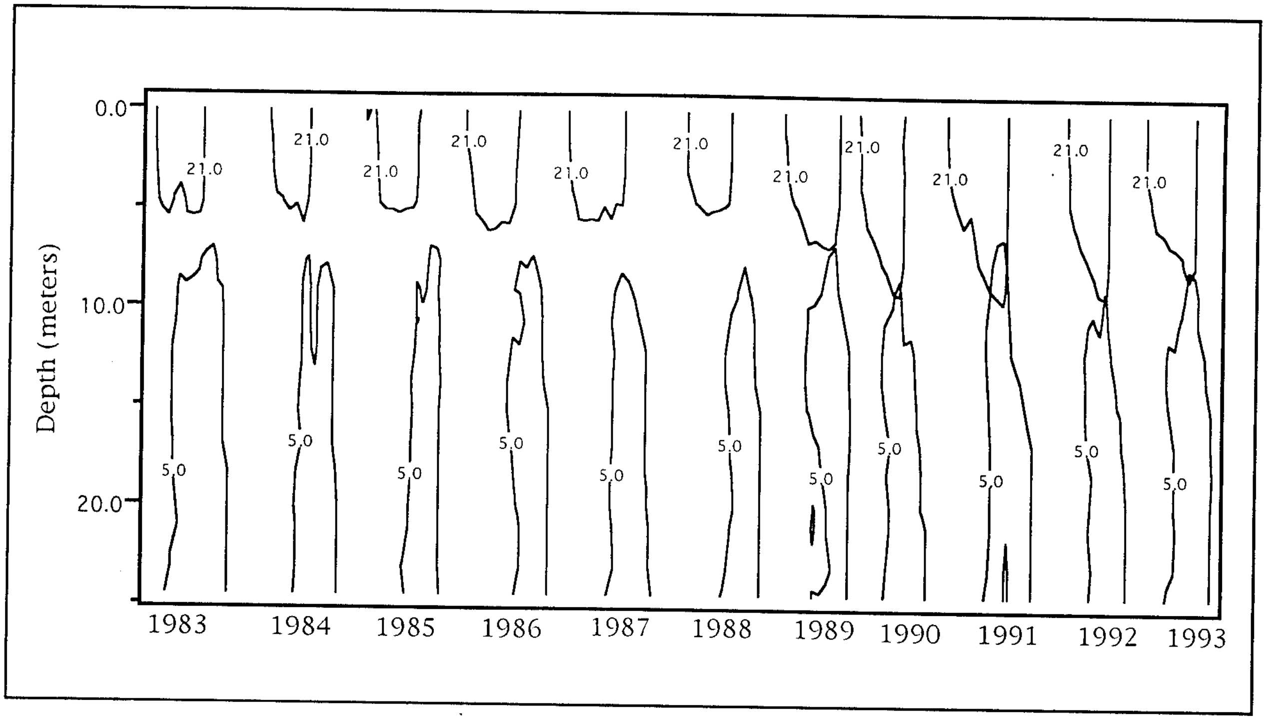


*Figure 2. Station M-4*

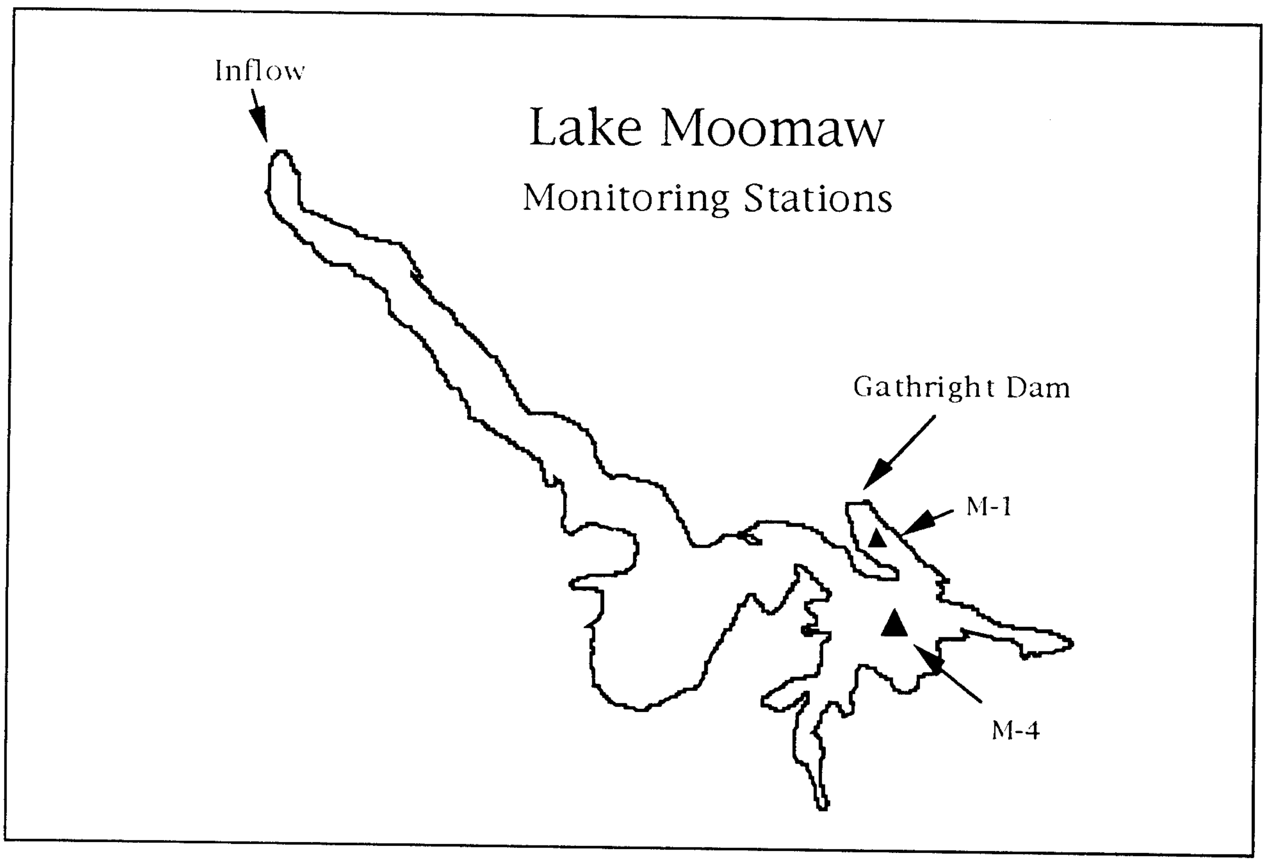


*Figure 3. Monitoring station locations*

Optimal trout habitat that enhances the productivity and growth of trout has been identified by the Commonwealth of Virginia as water temperature below 21 °C and dissolved oxygen concentrations at or above 5.0 mg/L. This zone of optimal trout habitat is represented by the area below the 21 °C contour and above the 5-mg/L dissolved oxygen contour.

The most obvious change in the temperature profiles as a result of providing downstream coldwater releases from 1990 to 1993 is the increase in the depth of the 21 °C contour by about 3 m (9.8 ft). This increase in depth of the 21 °C contour has effectively reduced the volume of trout habitat available within the reservoir. The modification in the method of providing downstream cold-down releases by blending the releasing water with upper and lower water quality ports in 1993 does not appear to have either a beneficial or adverse effect on the 21 °C contour within the reservoir.

The dissolved oxygen contour is somewhat erratic in a year-to-year comparison because of the many mechanisms that affect its concentration and distribution. The general shape and size of the 5-mg/L dissolved oxygen contour between 1990 and 1993 are reasonably close to the shape and size of contours in previous years. Therefore, the coldwater release scheme does not appear to affect the dissolved oxygen distribution.

# Trail Creek Sedimentation Study

*by*
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## Introduction

The need for channel maintenance dredging arises from the periodic buildup of shoal areas in the Federal channel that create navigation hazards. At the present time, the sediment being deposited in the Michigan City Federal channel includes silt from the Trail Creek watershed, sloughage of channel sides, and deposition of littoral drift at the harbor entrance. This deposition is not uniform throughout the channel areas. Apart from the outer harbor entrance, where littoral drift is the primary sedimentation source, there are two sources believed to contribute to sediment deposition. The principal source is movement of sandy materials from Trail Creek downstream into the Federal channel. Secondary sources of deposition are from combined sewer overflows, urban runoff, and other discharge flows. These materials combine and are deposited in the Federal channel. The net result of this process is that the sediments in some portions of the Federal channel are contaminated and not suitable for open-lake disposal. It is believed that sediments upstream of the Federal channel are clean and become contaminated as they travel through the Federal channel. Capturing these sediments before they enter the Federal channel by constructing a sediment trap will result in a substantial reduction in the volume of sediments deposited, reduce the frequency of required maintenance dredging, and provide clean sediments suitable for beneficial use. The location of the proposed sediment trap is immediately upstream of the Federal channel.

## Watershed Characteristics

Trail creek is a small tributary to Lake Michigan and drains approximately 59.1 square miles. The long-term average flow for the stream is 72.6 cfs. Approximately 70 percent of land use in the basin is agricultural, beginning from the source until the creek reaches the city limits. The remaining 30 percent is heavily developed, and land use is mainly urban residential and industrial. Soils within the Trail Creek basin are composed mostly of sand. All soils within the basin are highly transmissive because of their high sand content.

There are 10 combined sewer overflow (CSO) structures that discharge to Trail Creek. The city Sanitary Department is currently undertaking a plan to separate sanitary and storm sewers. The completion of this project should alleviate one of the larger sources of river sediment contamination within the Federal channel.

## Data Collection

In September 1991, a sampling program was implemented by the U.S. Army Corps of Engineers (USACE) to determine the physical and chemical characteristics of the sediments both within the Federal navigation project and upstream of the Federal channel. The purpose of the data collection was twofold. By sampling both within and out of the Federal channel, a transition point may be established between uncontaminated and contaminated sediments. Additionally, the data provide information for

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use in the development of a sediment transport model.

The U.S. Geological Survey (USGS), under contract with USACE, has been operating and maintaining a sediment gauge on Trail Creek in order to determine sedimentation rates upstream of the Federal channel. Sedimentation data gathered from this gauge will be used to develop a sediment discharge rating curve. The rating curve provides information needed for modeling studies.

A total of 19 sediment grab samples, 7 sediment core samples, and 3 soil core samples were collected. Thirteen locations were in the Federal channel, and thirteen locations were upstream of the Federal channel. A core sample was taken at the proposed sediment trap location. Other samples were taken throughout Trail Creek to provide a characterization of the entire system. The three soil core samples were collected at upland sites in order to determine background contaminant levels specific to the Trail Creek basin. These samples were taken at sites representative of three basin land-use types: woodland, urban mixed use, and industrial. The results of the testing are summarized in Table 1.

## Contaminant Distribution Trends

Because the location of the proposed sediment trap is immediately upstream of the Federal channel, it is useful to examine the chemical data in two groups, the Federal channel and Trail Creek. Table 1 presents average sediment chemical concentrations in Trail Creek, the Federal channel, soil samples collected in the Trail Creek basin, and Indiana statewide background levels. State background levels were determined by the Indiana Department of Environmental Management (1988/1989). Table 1 indicates that sediments in the Federal channel have higher average chemical concentrations for 11 of 13 parameters compared with Trail Creek sediments. Also, the majority of chemical constituents in Trail Creek sediments are below both statewide sediment background levels and ambient soils from the Trail Creek basin, indicating anthropogenic sources are not impacting this region of the creek.

Overall, sediments upstream of the proposed sediment trap (just upstream of the E street bridge) contain substantially lower chemical concentrations than sediments collected from the Federal channel. Both the nutrient and metal concentration profiles gradually increase inside the Federal channel, reaching a peak in the area of the first turning basin.

# Sediment Transport

## Sediment Loading

Records of dredging operations and sounding data gathered between 1970 and 1992 were used to estimate the average annual sediment loading to the Federal channel. The average represents the total sediment loading to the Federal channel and does not differentiate between sedimentation from land erosion in the channel, sedimentation in the outer harbor from littoral drift, or deposition from upstream Trail Creek. Sediment loading to the

**Table 1**
**Sediment Chemistry Averages**

| Parameter | State Background | Upland Soil | Trail Creek | Federal Channel |
|---|---|---|---|---|
| Total CN | <0.1 | 0.46 | 0.15 | 0.32 |
| TKN | 1,500 | 440 | 251 | 209 |
| Total P | 610 | 273 | 145 | 336 |
| NH3-N | — | <0.3 | 8.5 | 63.5 |
| Hg | 0.44 | 0.05 | <0.02 | 0.10 |
| Pb | 150 | 25.1 | 3.3 | 16.3 |
| Zn | 130 | 39 | 17 | 107 |
| Ni | 21 | 4.4 | 3.8 | 7.6 |
| As | 29 | 4.2 | 1.7 | 1.7 |
| Cd | 1.0 | 0.8 | 0.6 | 1.8 |
| Cr | 50 | 4.3 | 3.1 | 12.1 |
| Cu | 20 | 17.3 | 4.2 | 16.1 |
| PCBs | 0.022 | <0.02 | 0.04 | 0.09 |

Notes:
All units milligrams/kilograms dry weight unless otherwise noted.
Upland soil concentrations are averaged from three samples.
Federal channel concentrations are averaged from 13 samples.
Trail Creek concentrations are averaged from 13 samples.
State background levels taken from Indiana 305(b) Report.
PCBs = polychlorinated biphenyls.

Federal channel was estimated to be 8,078 tons per year.

Within the Federal channel, the major sources of sediment loading are urban runoff, combined sewer overflows, and other urban discharges. If runoff from these sources is the major contributor to sedimentation within the channel, a sediment trap located upstream of the channel would not be beneficial. Therefore, it is important to quantify the amount of sediment delivered to the channel from urban sources. The quantity of suspended sediment moving into the Trail Creek navigation channel from upland areas of the Trail Creek basin was determined by the USGS (USGS 1992). Statistical analysis of the suspended sediment data indicated an average annual sediment loading of 6,180 tons per year just upstream of the Federal channel. Other minor sources were estimated to contribute 700 tons per year, bringing the total load delivered to the Federal channel to 6,880 tons per year. Based on these estimates, approximately 1,198 tons per year, or approximately 15 percent, of the total estimated sediment loading to the Federal channel comes from sources along the channel.

## Sediment Transport Model

A sediment transport model was developed in order to predict the feasibility of constructing a sediment trap upstream of the channel. The one-dimensional sediment transport model, HEC-6, developed by the U.S. Army Hydrologic Engineering Center, was used. The HEC-6 model was used to simulate sedimentation in Trail Creek for a 20-year period using mean daily flows measured from a USGS stream gauge.

Two simulations were run for the 20-year period; one with a generic sediment trap in place, one without the sediment trap. Both simulations assumed 96,807 tons of sediment was dredged from the channel, to a depth of 2 ft below project depth. Four subsequent dredgings were simulated, one every 5 years. In each of these five events, the channel was dredged only to project depths. The "modeled" sediment trap consisted of a stretch of channel beginning just upstream of the Federal channel and extending 2,300 ft. This portion of the channel was dredged 6 ft below project depth and to a width of 80 ft. As before, dredging of the trap was performed at 5-year intervals, down to project depth.

The results of the model simulations are shown in Table 2. The numerical results should not be construed as absolute values. A one-dimensional, steady-state model will provide an order of magnitude estimate only.

**Table 2**
**Sedimentation Model Results**

| Year | Amount of Sediment Dredged: No Trap Channel | Trap | With Trap Channel |
|---|---|---|---|
| 1969 | 96,807 | 71,671 | 96,807 |
| 1974 | 6,140 | 25,470 | 0 |
| 1979 | 25,294 | 34,102 | 0 |
| 1984 | 28,086 | 28,994 | 0 |
| 1989 | 24,619 | 26,777 | 0 |
| Total[1] | 180,946 | 187,014 | 96,807 |
| Total[2] | 84,139 | 115,343 | 0 |
| Residual[3] | 48,366 | 30,694 | |
| Inflow to Lake[4] | 75,870 | 82,304 | |

Note: All units are tons.
[1] Total volume of sediment dredged including initial dredging in 1969.
[2] Total volume of sediment dredged excluding initial dredging in 1969.
[3] Volume of sediment that accumulated between project depth and depth of overdredging.
[4] Volume of sediment (silt and clay) that flows into Lake Michigan. A "no action" simulation (no dredging) produced a sediment inflow to lake of 82,523 tons.

Without the sediment trap, 84,139 tons of material were dredged during the 20-year simulation, excluding the initial dredging. Additionally, 48,366 tons of residual sediment, which accumulated in the channel between the project depth and the depth of overdredging, was not dredged. A total of 132,505 tons of sediment were deposited in the Federal channel during the 20-year simulation, or about 6,625 tons of sediment per year. This value is approximately 82 percent of the average annual amount of sediment deposition calculated from dredging records and sounding data.

The 20-year simulation that included the sediment trap resulted in no need for dredging within the channel, although residual sediment did accumulate below project depth. Construction of the trap required the removal of 71,671 tons of material. The total amount of material dredged from the sediment trap during the 20-year simulation was 115,343 tons. The model indicated that the sediment accumulated in the trap would be predominantly coarse-grained material with about 5-percent fines. Interestingly, the total amount of sediment to reach Lake Michigan remained essentially the same in the presence of a sediment trap. This is because only coarse-grained sediments will have sufficient terminal velocities to settle out of suspension in the trap. The smaller fine-grained particles, with substantially lower terminal velocities, remain in suspension and continue downstream. The model shows that only silts and clays reach the lake. Again, the model results provide order of magnitude estimates, utilizing a single trap size.

## Conclusions

The intent of this investigation is to make a reconnaissance level assessment of the practicality of building a sediment trap. The 20-year sedimentation model simulation shows that the proposed sediment trap, 2,300 ft long, 80 ft wide, and depth of -12 ft LWD, could collect large quantities of upstream sediments before they travel into the navigation channel. Hence, the trap would reduce the amount of maintenance dredging required. For a detailed description of this study, see the final report issued by the Chicago District (USACE 1992). A more detailed analysis is needed to get a better estimate of the potential effectiveness of the sediment trap. This study would include a calibration of the model based on dredging records over the entire channel, the impact of higher short-term flows, and the effect of varying lake levels. Also, the physical size of the sediment trap should be varied, and the corresponding results analyzed on a cost-benefit basis to determine the optimum size. The cost-benefit analysis would weigh a one-time construction cost against maintenance costs required to keep the trap functional and continued dredging of the Federal channel without the sediment trap.

This initial, reconnaissance level report is intended to be only the first of many activities that need to be completed before a decision on whether or not to build a sediment trap is made. A feasibility report and ultimately construction of a prototype trap will allow for verification and refinement of the sedimentation model and provide useful information on both cost and function of the proposed sediment trap.

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# Effects of Motorized Watercraft on Sediment Quality at Fox Chain O'Lakes in Northern Illinois

*by*
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## Introduction

During 1992, the U.S. Army Corps of Engineers, Chicago District, investigated the impacts of motorized watercraft on water and sediment quality in the Fox River Chain O'Lakes. This investigation was part of an ongoing effort to develop an Environmental Impact Statement on the impacts of motorized watercraft on the Chain O'Lakes.

The focus of this paper will be on the impacts of motorized watercraft on sediment quality at the Chain O'Lakes. This paper and the accompanying presentation will present pertinent literature, the Plan of Study, collection and analysis of the samples, the results, and lessons learned in the process.

### The Chain O'Lakes

The Fox Chain O'Lakes is located in northern Illinois, approximately 60 miles northwest of Chicago; it consists of nine interconnected lakes located on the Fox River in Lake and McHenry counties. The Chain O'Lakes was created when the McHenry Dam was constructed on the Fox River in 1907, raising the water level and connecting the lakes. Additional channels were cut between the lakes. Figure 1 shows a conceptual map of the Chain O'Lakes.

### Environmental Impact Statement

The Chicago District enacted a 1-year moratorium on processing new permits for construction of boat slips in the Fox River Chain O'Lakes. During that moratorium, the Chicago District prepared an Environmental Impact Statement (EIS) on construction of new docks in the Chain O'Lakes. The purpose of the EIS was to determine if motorized watercraft affect water and sediment quality. The results of the EIS will be used to initiate a District permit-processing policy for construction of new boat slips on the Chain O'Lakes. The EIS presented the cumulative environmental impacts of potential permitting actions in the area. In addition, waterway management recommendations were developed in the EIS for use by local governing bodies.

The primary focus of the sediment quality investigation was impacts at refueling areas.

## Sediment Quality Investigation

Most earlier studies assessed the impact of motorized watercraft on water quality. The parameters of concern suggest impacts might also be associated with sediment.

Gasoline from boats could lead to a sediment quality problem. Wagner (1991) estimated that two-cycle engines built prior to 1975 accumulate roughly 55 percent of the fuel in the crank case and discharge it into the water. Newer engines have a much higher efficiency and are estimated to discharge less than 1 percent of their fuel. Because of the durability of engines built prior to 1975, Wagner and others have estimated that as of 1991, roughly 25 percent of the pre-1975 boat engines were still in use.

The Chicago District contacted marinas in the Chain O'Lakes area and found that nearly

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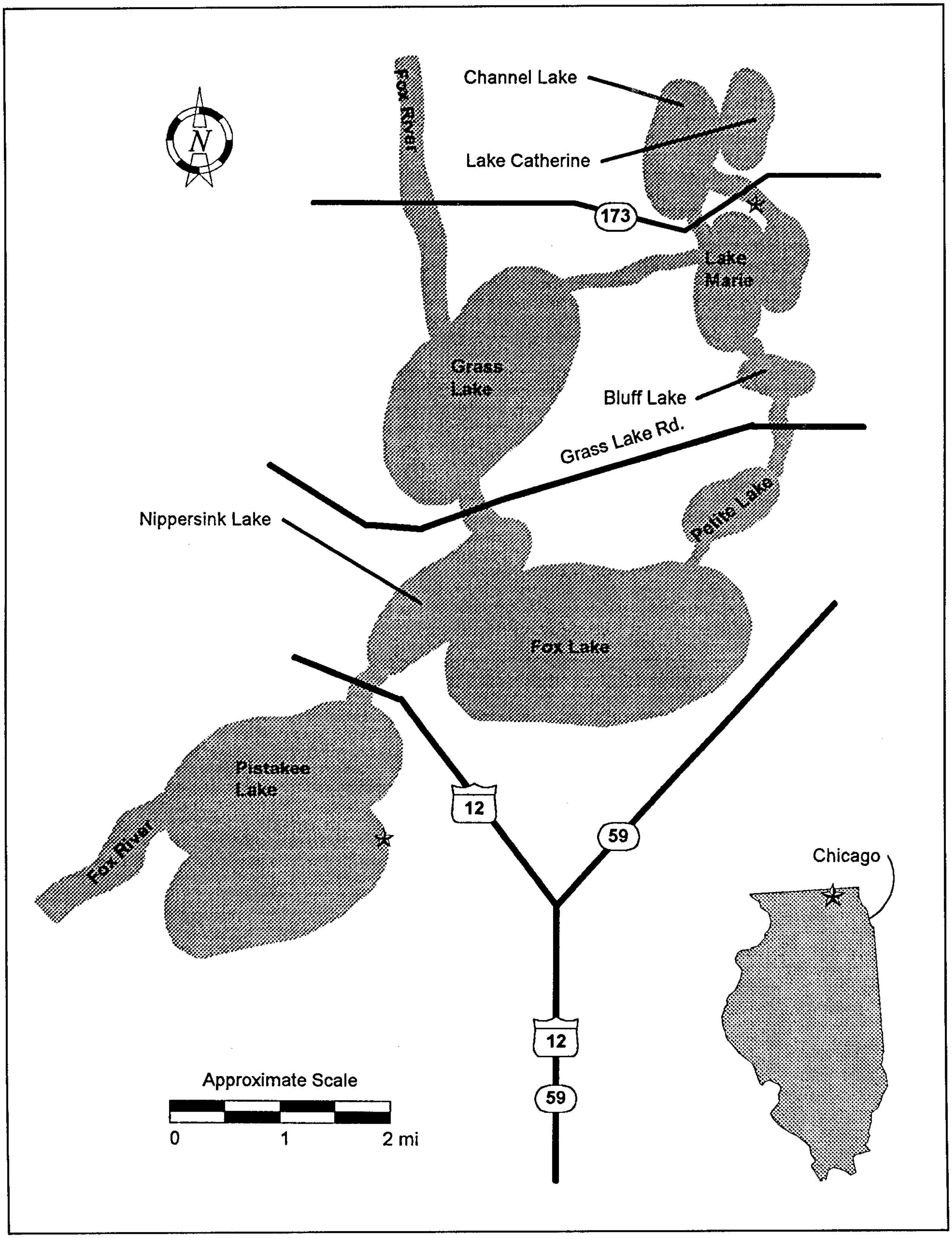


*Figure 1. Conceptual map, Chain O'Lakes*

all sold lead additives for gasoline. Boat engines manufactured prior to 1977 require lead additives. The marinas contacted indicated that they sold the lead additive, and one marina even indicated that they had a special storage tank into which the additive was directly mixed.

There is also the potential for impacts from engine exhaust. Jackivicz and Kuzminski (1973) indicate that as much as 70 to 80 percent of the lead burned in pre-1975 engines is released through the exhaust. If 55 percent of the fuel is ejected into the water (Wagner 1991) and 70 to 80 percent of the lead from the burned fuel is also released as exhaust, this suggests that as much as 85 to 90 percent of lead in the fuel was, and still is, released into the environment. Other studies found little or no increase in lead concentrations in the water column, but did not examine sediment quality.

In their study of dredge material disposal options, Kothandaraman et al. (1977) found that background lead concentrations in Chain O'Lakes sediments were approximately 20 mg/kg in sediment deposited prior to 1840 and approximately 60 mg/kg in sediment deposited after 1840. These authors attribute the increase in lead concentration to the advent of engines that burn leaded fuel. They found sediment in one marina in Pistakee Lake with lead concentrations of approximately 442 mg/kg.

## Objectives

The objective of the study was to quantify the impacts of recreational boating on water and sediment quality and distinguish boating impacts from baseline conditions.

## Methods

The sediment quality investigation focused on refueling areas. It is reasonable to assume impacts associated with spillage of fuel, fuel additives, and exhaust emissions (PAHs) would exist at higher concentrations in refueling areas, where boat traffic would be heaviest.

Two marinas were chosen for sediment and water collection. The stars shown in Figure 1 on Pistakee Lake and between Channel Lake and Lake Marie indicate the locations of the two marinas. Two sets of samples were collected at each marina, one in July, the other in September. Both sampling expeditions occurred immediately after busy boating weekends.

Samples were collected in a roughly radial pattern as shown in Figure 2, using a petite ponar dredge for the sediment samples and a Kemmerer bottle for the water samples. The sediment samples were analyzed for lead, zinc, cadmium, chromium, aluminum, polynuclear aromatic hydrocarbons (PAHs), and total organic carbon (TOC). The water samples were analyzed for benzene, ethylbenzene, toluene, and xylene (BTEX).

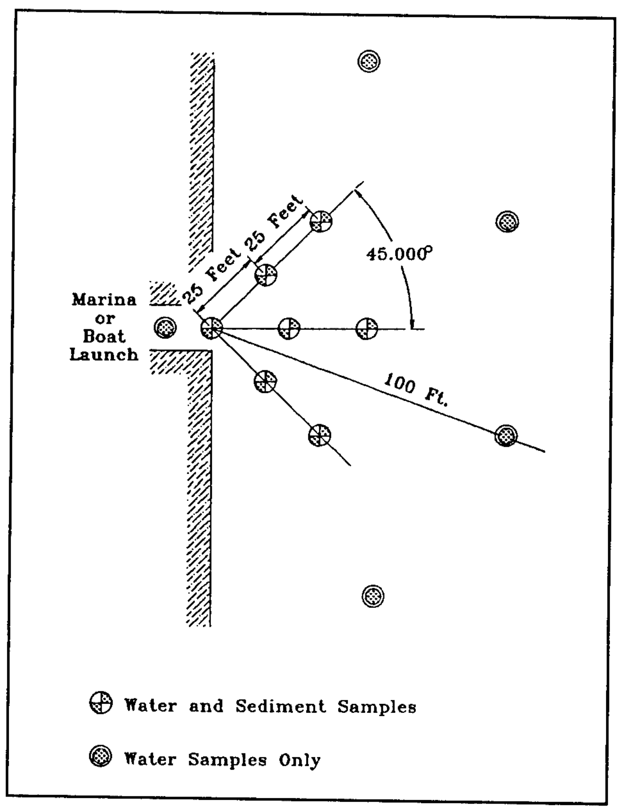


*Figure 2. Sediment and water-sampling pattern*

There was a statistically significant relationship ($p < 0.05$) between concentration of lead in the sediment and distance from the refueling pump. The concentration of lead decreased as distance from the pump increased. Statistical analysis showed correlation coefficients of $r = 0.69$ for marina 1 and $r = 0.71$ for marina 2. Figure 3 shows a three dimensional plot of the lead concentration in the sediment at marina 1. The concentration of lead at marina 1 ranged from 19.7 to 413 mg/kg. At marina 2, the lead concentration ranged from 30.5 to 60.5 mg/kg. The other metals were detected at elevated concentrations, but appeared to have no relation to location of the refueling station. Chromium concentrations ranged from 14.4 to 767 mg/kg in marina 1 and from 11.7 to 227 mg/kg in marina 2. Cadmium ranged from 1.95 to 6.78 mg/kg at marina 1 and from 2.75 to 4.87 mg/kg at marina 2. Zinc ranged from 16 to 125 mg/kg at marina 1 and from 5.87 to 98.3 mg/kg at marina 2. Aluminum ranged from 2,220 to 12,200 mg/kg at marina 1, and from 3,040 to 5,670 mg/kg at marina 2. PAHs were not detected in any of the sediment samples. TOC was present in the sediment samples, but did not appear to be related to the location of the refueling area.

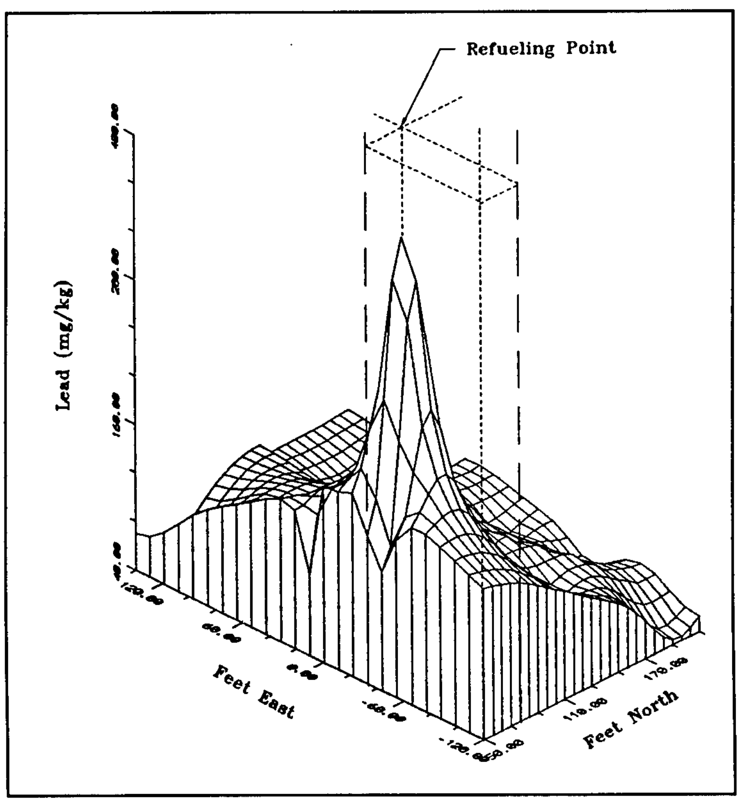


*Figure 3. Lead concentration in sediment near refueling point*

BTEX analysis of the water samples indicated detectable concentrations of toluene at both marinas, benzene and xylene only at marina 1, and no ethylbenzene at either marina. The BTEX concentrations were not related to distance from the refueling location.

## Discussion

The BTEX analysis did not indicate the presence of water column impacts at the refueling areas. In retrospect, it would have been more appropriate to analyze the sediment samples for Total Recoverable Petroleum Hydrocarbons (TRPH). It is likely that the BTEX constituents are too volatile to observe in the water column under most conditions, while TRPH analysis would have captured the less volatile petroleum constituents in the sediment.

Though the farthest sampling point was approximately 200 ft from the refueling station, there was no correlation between distance from the pumps and parameters other than lead. Thus no conclusions can be drawn regarding potential source or migration of these contaminants. Additional stations, perhaps ranging to one-half mile away, might provide a better comparison of background contaminant levels relative to concentrations near marina refueling stations.

## Conclusions

Spillage or leakage of leaded gasoline additives is contributing to increased lead concentrations in sediments near refueling stations on the Fox Chain O'Lakes. Lead contamination from watercraft engines through the discharge of exhaust or

unburned fuel would tend to be widespread, but the relationship observed between lead concentrations and fuel dock location in this study suggests refueling areas are a point-source of lead contamination in lake sediments. Removal of contaminated sediment, improvements in fuel delivery systems, and gradual elimination of engines that require leaded fuel will help improve sediment quality near recreational marinas.

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# Finger Lakes Biological Response Study

*by*
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## Introduction

The Corps of Engineers has a mission to manage the physical and chemical conditions of regulated rivers. The Finger Lakes Habitat Rehabilitation and Enhancement Project was designed to improve aquatic habitat in a set of Mississippi River floodplain lakes affected by construction and operation of the Mississippi River 9-Foot Channel Navigation Project. I would like to describe a study of the Finger Lakes that goes beyond routine water quality monitoring and habitat evaluation to determine some of the ecological responses to management of an aquatic system.

### Upper Mississippi River System Environmental Management Program (UMRS-EMP)

The UMRS-EMP was authorized by the Water Resources Development Act of 1986. The EMP was originally authorized for 10 years, and the program was extended for an additional 5 years through the year 2002. The program is a partnership between the Corps, the National Biological Survey (NBS), the U.S. Fish and Wildlife Service (USFWS), and the five UMRS States. Approximately two-thirds of the $19.5 million annual EMP funding is directed to Habitat Rehabilitation and Enhancement projects (HREP).

### HREP Projects

HREP projects are nominated for construction by the EMP partner agencies. The projects are planned by the Corps in coordination with the States, the USFWS, and the NBS. The projects are designed and constructed by the Corps St. Paul, Rock Island, and St. Louis Districts. The projects employ a variety of river habitat management measures, including hydrologic modification, dredging, island construction, and vegetation planting. Over 60 HREP projects are in various stages of planning, design, construction, and completion. All of the projects are being monitored to determine project performance: the degree to which habitat objectives are met. A few of the projects have been selected for more intensive biological response studies, to determine the response of vegetation and animal populations to the habitat management measures, and the causal mechanisms influencing them.

## Finger Lakes

### Location

The Finger Lakes (Figures 1 and 2) are a connected system of five abandoned channel floodplain lakes immediately downstream of Lock and Dam 4 on the Upper Mississippi River (river mile 752) near Wabasha, MN.

### Preproject Conditions

Conditions in the Finger Lakes have been investigated during 2 full years of pre-HREP project investigations (Barko et al. 1993, 1994). The lakes were isolated from river flow by construction of the Lock and Dam 4 earthen dike in 1934. The lakes cover 176 ha at low water and are shallow with an average depth of just over 1 m. The lakes have a high

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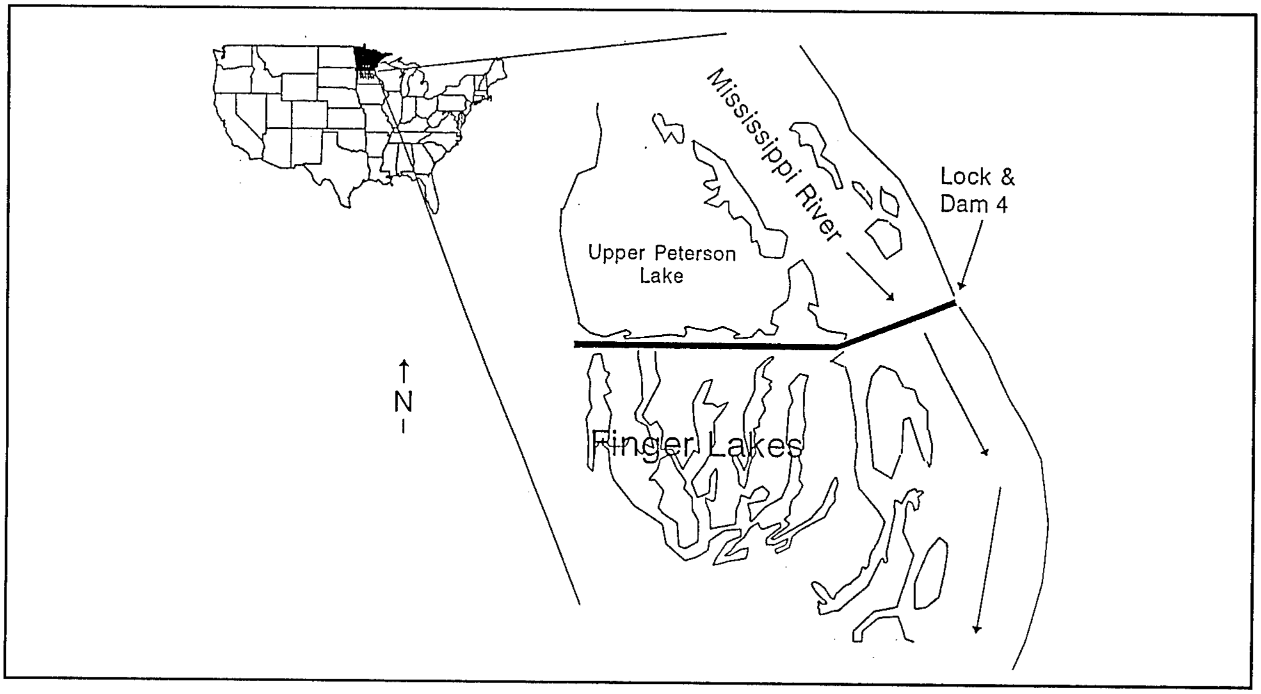


*Figure 1. Location of Finger Lakes, Pool 5, Upper Mississippi River*

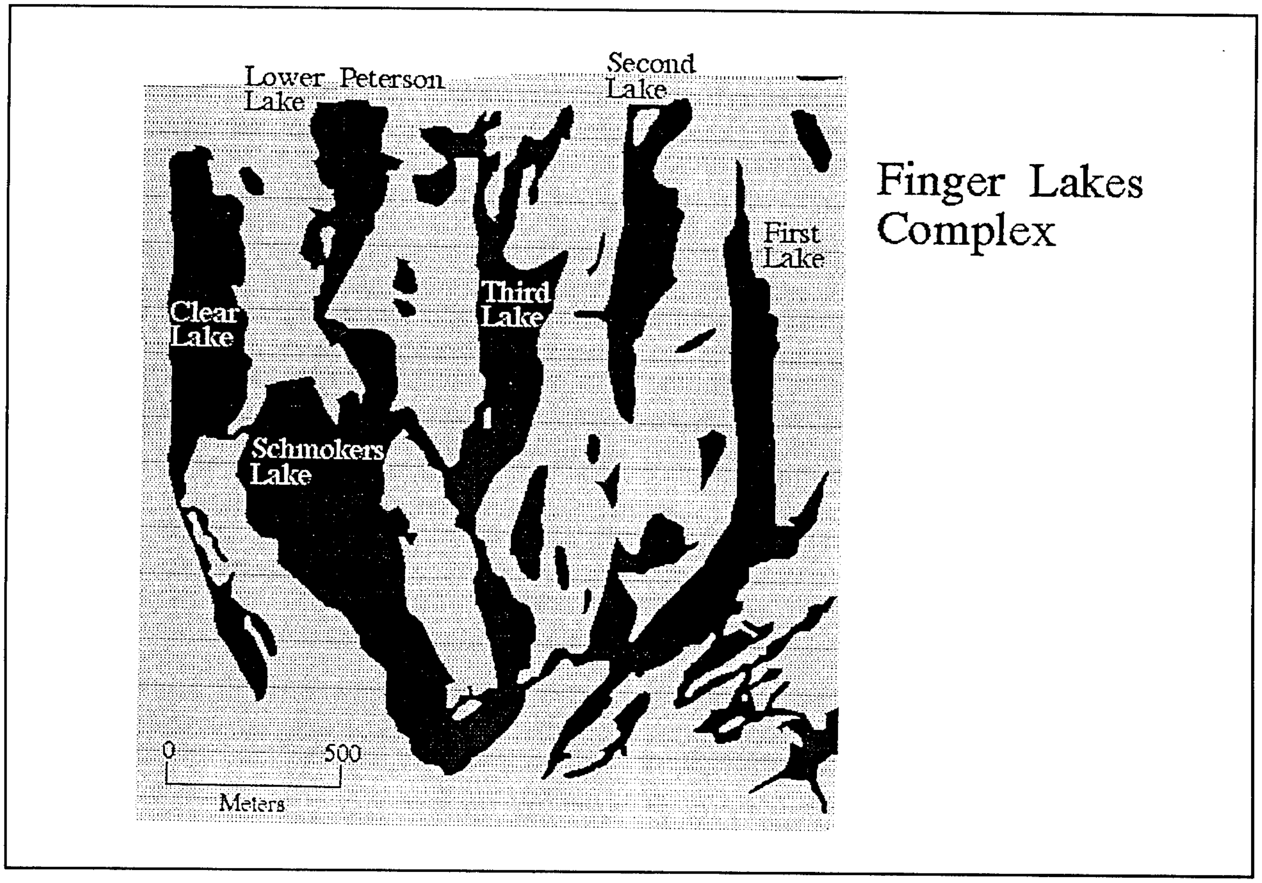


*Figure 2. Finger Lakes, Pool 5, Upper Mississippi River*

bottom area to volume ratio, are eutrophic, and some are heavily vegetated. Water entered the lakes when the tailwater stage at the lock and dam rose and through a culvert in the dike installed in the 1960s into Lower Peterson Lake.

Water quality conditions were quite different between the lakes receiving flow and those that did not. Lower Peterson and Schmokers Lakes had flow. Conditions in them were riverine. First, Second, and Third lakes were heavily vegetated with macrophytes. Clear Lake was influenced by groundwater inflow, supported blue-green algae blooms, and had few macrophytes.

Winters in Minnesota are cold, with below 0 °F air temperatures common in December through February. Ice cover lasts from early December well into March. In northern rivers, many lentic fishes such as largemouth bass, bluegills, and crappies need winter refugia. Many fishes have limited ability to maintain position in flowing water at temperatures approaching 0 °C (Bodensteiner and Lewis 1994). Availability of overwinter habitat is thought to be a limiting factor for lentic fishes in the UMRS (Pitlo 1992). The Finger Lakes support resident populations of bass, bluegills, and crappies, but suitable winter habitat conditions were constrained by cold temperatures (near 0 °C) in the flowing portions of the system and dissolved oxygen depletion in the nonflowing lakes (Figures 3 and 4). Fish kills have occurred in the Finger Lakes during late winter.

In summary, the problems with aquatic habitat conditions in the Finger Lakes prior to HREP project construction were as follows:

- Isolation from river flow.
- Shallow depth.
- Low-water temperatures during winter in the flowing parts of the system.
- Dissolved oxygen depletion during winter in the nonflowing parts of the system.

## Finger Lakes HREP Project

The Finger Lakes HREP project objectives are to improve winter habitat conditions for centrarchid fishes and to reduce winter fish kills. The project consists of three new gated culverts through the Lock and Dam 4 earthen dike to convey water into the lakes. The existing culvert into Lower Peterson Lake was retrofitted with a control gate.

## Finger Lakes HREP Biological Response Study

The study is an interdisciplinary, interagency cooperative effort that began in 1991. The U.S. Army Engineer Waterways Experiment Station Eau Galle Laboratory, the U.S. Fish and Wildlife Service National Fisheries Research Laboratory, La Crosse, WI, and the U.S. Fish and Wildlife Service Environmental Management Technical Center, Onalaska, WI (both now in the National Biological Survey), and the Minnesota Department of Natural Resources are study participants.

Study objectives are to determine system response to flow introduction:

- Physical/chemical conditions.
- Vegetation.
- Fish.
- Macroinvertebrates.

Another objective was to determine the optimal flow rates through the culverts to suitable overwintering habitat for centrarchid fishes. The fisheries investigations were designed to determine if the project-induced changes in habitat conditions result in changes in centrarchid fish populations.

Bathymetry, substrate type, and vegetation surveys were performed. Physical/chemical conditions were monitored year-round, and intensive spatial surveys were conducted to determine the spatial distribution of aquatic habitat conditions. Figure 5 illustrates Third

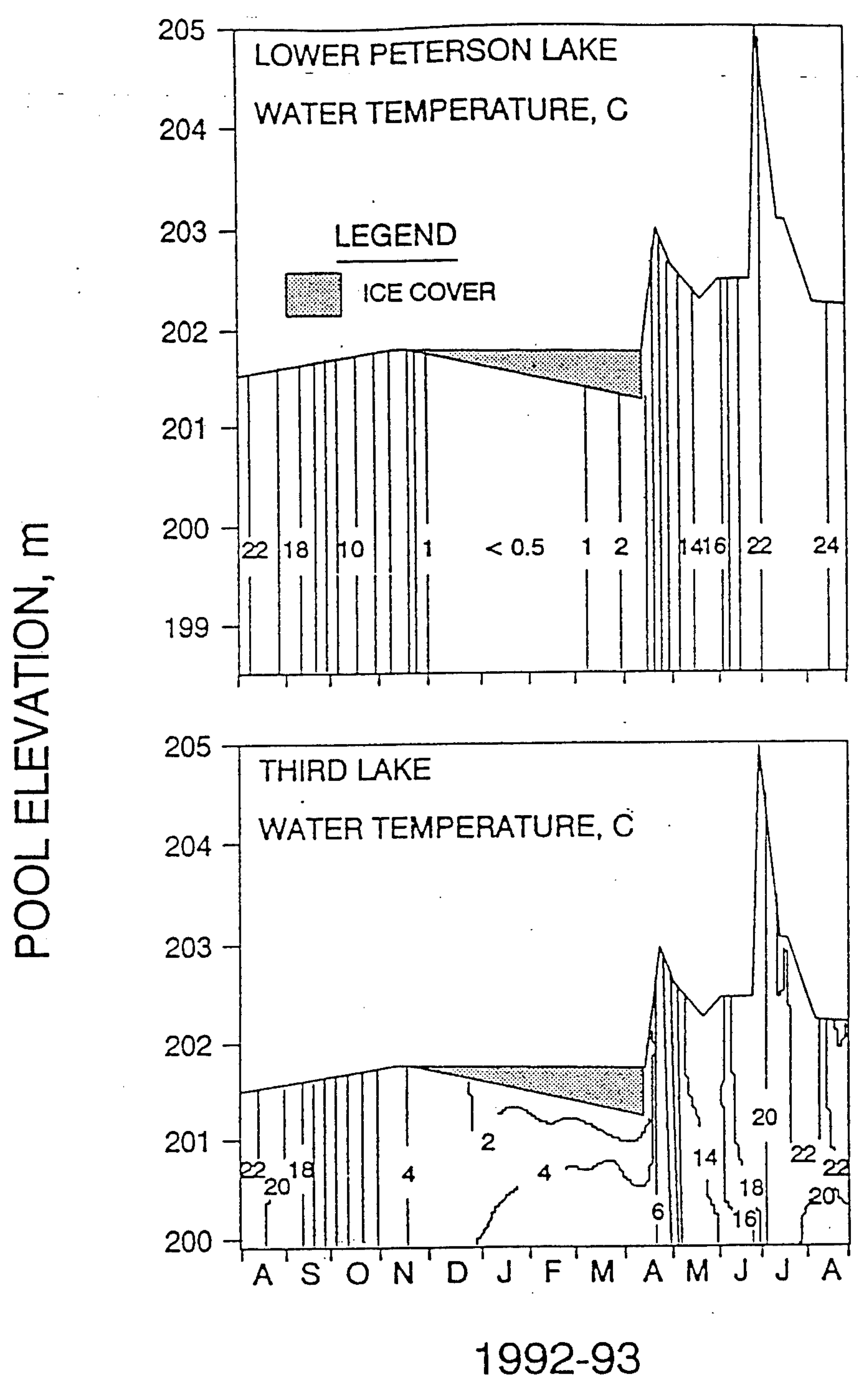


*Figure 3. Winter water temperature conditions in Lower Peterson Lake (flow through) and Third Lake (no flow), 1992-1993*

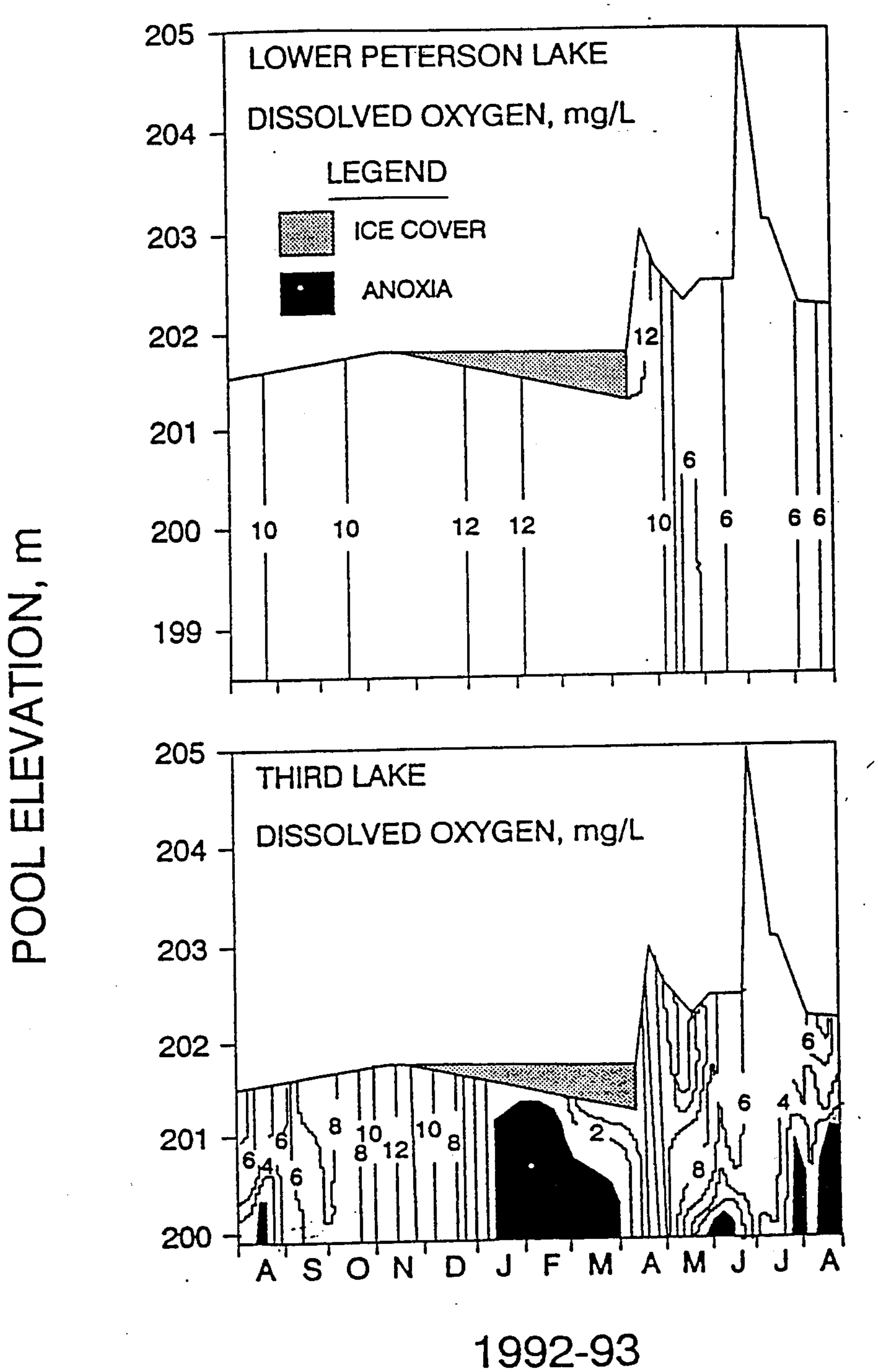


*Figure 4. Winter dissolved oxygen conditions in lower Peterson Lake (flow through) and Third Lake (no flow), 1992-1993*

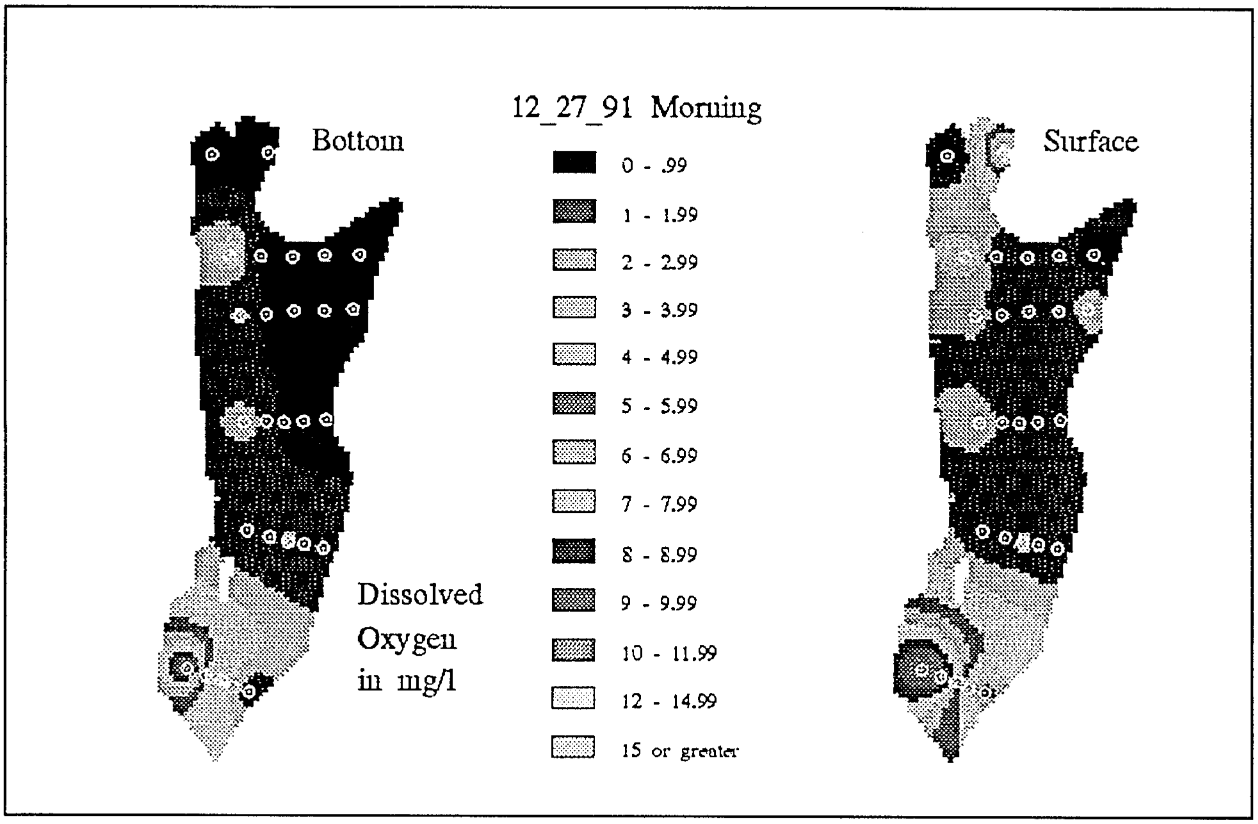


*Figure 5. Spatial distribution of dissolved oxygen within Third Lake, Finger Lakes, December 27, 1991*

Lake in a typical pre-HREP project state of winter anoxia. The hydrology of the system was monitored, and winter dye studies were performed to determine flow paths and rates of hydraulic exchange.

Fish sampling by fyke nets and electrofishing revealed a typical UMRS backwater fish assemblage, dominated by bluegills and crappies. Population sizes were estimated in the spring and fall by mark/recapture. Creel surveys were conducted to determine exploitation rates. Growth rates and diet were determined. Radio telemetry tracking of fish movements revealed the patterns of habitat use.

Diet studies showed that the Finger Lakes were a benthic-based food web. Macroinvertebrates were found primarily on aquatic plants and in the sediments within plant beds.

Telemetry studies showed that both bluegills and crappies have winter habitat preferences:

| | Prefer | Avoid |
|---|---|---|
| Dissolved oxygen, mg/L | >2 | <1 |
| Current, cm/s | 0 | >1 |
| Water temperature, °C | >3 | <1 |

## Flow Rates

Flow rates through the culverts were set to attain the balance of overwintering conditions needed by fish. Observed rates of winter oxygen depletion of 0.2 to 0.3 mg $L^{-1}$ $day^{-1}$, oxygen concentration of the inflowing water (>10 mg/L in winter), and lake volumes were used to calculate the needed culvert flow rates to maintain target dissolved oxygen concentrations of >3 mg/L. Flow rates needed to offset

winter oxygen depletion while avoiding low-water temperatures were quite low, in the range of 2 to 5 cfs for each lake.

## Conclusion

Project construction was completed in November 1993, and the culvert flow rates were set. We have already observed major changes in winter habitat conditions in the Finger Lakes, with increased volume of suitable overwintering habitat for lentic fishes. We will continue monitoring to document changes in the system. It is difficult to forecast biological responses to the hydrologic modifications because of the many interacting factors, but we will determine the "bottom line" changes in physical/chemical conditions, vegetation, macroinvertebrates, and fish populations.

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# Assessing Water Quality Impacts of Columbia River System Operating Strategies

*by*
*Bolyvong Tanovan*[1] *and Nancy Yun*[1]

## Introduction

The Columbia River System is a vast and complex combination of Federal and non-Federal facilities upon which Northwest residents have become dependent for power production, irrigation, navigation, flood control, recreation, fish and wildlife habitat, and municipal and industrial water supplies. Operation of the Federal Columbia River System is the responsibility of the Bureau of Reclamation, U.S. Army Corps of Engineers, and Bonneville Power Administration. The System Operation Review (SOR) is a study and environmental compliance process used by the three Federal agencies to analyze the impacts of alternative system operations and river-use issues. Its goal is to achieve a coordinated river system operation that better meets the current and future needs of all river users.

Most of the new needs emerged from actions required to enhance the survival of the anadromous fish on the main stem Columbia/ Snake rivers. These actions included releasing more flows and lowering reservoirs to increase water particle velocity (and hence reduce juvenile fish time of travel) and providing more spill to pass more fish over the relatively safer spillway route. In one alternative, spill as high as 80 percent of daily average flow was proposed. New system operating criteria and constraints must be defined now so they can be accounted for in the next round of Columbia River Treaty negotiations with Canada. The first Treaty-related agreement to expire, beginning in 1998, is the Canadian Entitlement Allocation Agreements, which divides power benefits between Canada and the United States. Directly affected is the operation of the 14 Federal dams on the Columbia and Snake rivers that have major influence on multiple-purpose system operation.

A three-stage process—scoping, screening, and full-scale analysis—was developed to address the many issues relevant to the SOR. A total of 90 system operation alternatives developed during the scoping were studied in the initial analysis. Preliminary analysis and screening eliminated many of these alternatives from further consideration. The following seven operating strategies including 21 alternatives were analyzed in the full-scale study: (a) Operation before the listing of Snake River salmon stocks; (b) Current (1993) Operations; (c) Flow Augmentation to provide more water to move juvenile fish more rapidly down the river; (d) Stable Storage Project Operation to minimize pool fluctuations for recreation and resident fish; (e) Natural River Operation to increase river velocity by drawing down one or all four lower Snake River reservoirs to near original riverbed levels; (f) Fixed Drawdown to draw down these reservoirs to spillway crest; and (g) Federal Resource Agency Alternatives to reflect operating strategies proposed by the fishery agencies.

## Methodology

### General

Because water temperature, dissolved gas, and sediment are both important to fish and can be affected by system operation, the water quality impact assessment of SOR system

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strategies was concentrated on those three parameters. Three different models covering the United States portion of the Columbia/Snake rivers system were used to predict impacts. Periods of emphasis were July-September for water temperature, April-September for total dissolved gas, and January-December for sediment. Current system operations served as the baseline.

## Project Data

Data on project outflows, reservoir pool elevations, and spill were developed separately by a system hydroregulation model, HYDROSIM, based on the regulation objectives specified for each alternative. These data covered a 50-year (1928-77) continuous simulation period, but only a selected number of years were used. Attempts were made to select a number of years that cause the alternatives to experience their best and worst performances at least once. Five flow years were selected for water temperature simulation, six years for total dissolved gas, and three years for sediments. The five flow years selected included 1929 (low), 1959 (medium high), 1962 (medium low), 1973 and 1974 (high). They provided a typical range of low-to-high pool elevations and flows at three major storage projects (Grand Coulee, Dworshak, and Brownlee). Three different weather conditions (below average, average, and above average temperature) were used in conjunction with each of the five simulated flow years. For dissolved gas, the years selected for the analysis were 1974 (high); 1938, 1959, and 1962 (average); and 1973 and 1977 (low). For sediments, 1973 was selected to be the low flow, 1959 the medium flow, and 1974 the high flow years.

## Risk and Uncertainties

During the screening phase, probabilistic analysis was used to test the sensitivity of model outputs to changes in model coefficients and data input. Maximum and minimum values for each variable, as well as probabilities of occurrence of each possible choice represented on the decision trees (a reflection of risk), were specified. A cumulative frequency distribution depicting the magnitude and probabilistic results for each impact was then generated. Similar analysis on a full-scale model would have to rely on Monte Carlo simulation. Because of the large number of variables involved and the need to develop the required computer routines, the analysis was not performed.

## Performance Indices

Performance indices were defined based on the number of days the predicted impacts exceed a given threshold during the simulation period. For water temperature, the threshold was the upper range of tolerable temperature for anadromous fish during the April through September period (17.2 °C or 63 °F). For total dissolved gas, the threshold was the current State standard of 110-percent saturation. Because this level is usually not lethal for fish species whose normal habitat is in water deep enough to provide adequate hydrostatic pressure compensation, two higher levels (120 and 130 percent) were also used. For sediments, performance indices were defined as total sediment transported in the first and fifth year of operation (initial high impact and equilibrium state, respectively).

## Ratings

Alternatives were rated in terms of how they were predicted to affect each of the three parameters based on the performance indices. This was done separately for each parameter and each runoff year by ranking the alternatives from 1 to 3 or 4 depending on the spread of the alternatives performance indices. The combined rating reflected by the sum of the annual rankings for all flow years represented the alternatives overall performance with respect to that particular parameter. At this point, the combined rating was translated into a system of "index of overall impact" based on a relative scale going from -2 to +2. By definition, the index of overall impact for the current operation (base case) was set equal to

0; all other alternatives were then assigned an index of overall impacts based on that definition and in direct proportion of their own total ratings. Each scale was interpreted as follows in relation to the base case: -2 = worst; -1 = worse; 0 = no change (from the base case); 1 = better; and 2 = best.

For dissolved gas, indices of overall impacts were assigned separately as outlined above for the 110-, 120-, and 130-percent saturation thresholds. The final indices of overall impact were then calculated as weighted sums of the individual indices. Weighing coefficients were 1.0, 1.5, and 2.0, respectively, to more heavily penalize alternatives that excess higher thresholds. For sediments, indices of overall impacts were directly related to the predicted volume of sediments transported.

## Computer Modeling

### Water Temperature Modeling

For water temperature, the one-dimension HEC-5Q model covering the Columbia/Snake rivers main stem from Grand Coulee and Brownlee Reservoirs to Bonneville Dam was used. This model was calibrated using data for the years 1984, 1985, and 1990, which represent lower Snake River's above average, below average, and average temperature years, respectively. Model output included daily water temperature at all dam locations. The target temperature for Dworshak Reservoir outflow was set at 45 °F, a temperature designed to maximize downstream temperature reduction and yet not too cold for fish immediately below the project.

### Dissolved Gas Modeling

The model used for this parameter is GASSPILL, a one-dimension model covering the Columbia and Snake rivers from Chief Joseph and Lower Granite dams to Bonneville Dam. GASSPILL was calibrated using daily data for 1984 and 1986, two of the most recent above normal spring runoff years observed in the Columbia River basin. Boundary conditions (contribution from Canada and the upper Snake River above Lower Granite Dam) had to be assumed.

### Sediment Modeling

Sediment modeling was only done in conjunction with drawdown alternatives and current operations only. HEC-6, a one-dimension, steady flow, mathematical sediment transport model was used in this case. It was calibrated for Lower Granite Reservoir using data for the 1975 normal reservoir operations and the 1992 drawdown test. To enable estimation of long-term accumulated effects, a 5-year simulation duration with an arbitrary rearranging of the three individual years was used. The results of the sediment studies were used as input to the HEC-5Q model to estimate sediment trapping efficiencies of the Lower Snake River dams operating under the proposed drawdown alternatives.

## Analysis Results

Sample results shown below (Table 1) are numbers of days the given thresholds are exceeded during the multiyear simulation period. They are related to Alternative 7a, one of the 21 alternatives assessed in the full-scale analysis.

Risk and uncertainties analysis was only conducted for the screening, using a commercial package software named SUPERTREE. Major variables included hydrology (what size runoff will occur), initial conditions at the start of the simulation based on what can be expected from headwater areas of Canada and Upper Snake River, and weather conditions. Sample graphical results are shown in Figure 1.

## Comparison of Alternatives

Application of the methodology outlined above is illustrated in Tables 2 and 3 for water temperature analysis.

**Table 1**
**Sample of Summary Results**

Water Temperature (Threshold = 17.2 °C)

| | Location | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DWR | BRN | OXB | HCD | LWG | LGS | LMN | IHR | GCL | CHJ | WEL | RRH | RIS | WAN | PRD | MNW | MNO | JDA | TDA | BON |
| Max | 42 | 80 | 81 | 84 | 86 | 87 | 88 | 89 | 62 | 63 | 65 | 78 | 78 | 80 | 81 | 91 | 94 | 93 | 93 | 91 |
| Ave | 8 | 74 | 74 | 74 | 83 | 83 | 84 | 88 | 39 | 46 | 51 | 59 | 60 | 66 | 67 | 77 | 89 | 88 | 89 | 89 |
| Min | 0 | 72 | 71 | 69 | 80 | 80 | 81 | 85 | 0 | 3 | 27 | 41 | 44 | 47 | 49 | 62 | 85 | 75 | 78 | 81 |

Dissolved Gas (Threshold = 110%)

| Station: | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max | 57 | 57 | 54 | 89 | 89 | 95 | 152 | 138 | 146 | 139 | 103 | 94 | 82 | 95 |
| Ave | 29 | 26 | 22 | 43 | 37 | 49 | 145 | 130 | 135 | 128 | 56 | 37 | 24 | 23 |
| Min | 20 | 15 | 10 | 25 | 18 | 31 | 136 | 123 | 116 | 110 | 30 | 18 | 3 | 0 |

Sediments (Predicted Sediment Load in tons at Snake River RM 120, inside Lower Granite Reservoir, 1st and 5th years).

| | 2 Month-Drawdown | | 4.5 Month-Drawdown | |
|---|---|---|---|---|
| | 1st Year | 5th Year | 1st Year | 5th Year |
| Minimum Pool | 500,000 | 500,000 | 1,000,000 | 500,000 |
| 33 ft | 900,000 | 700,000 | 2,100,000 | 900,000 |
| Natural streambed | 4,400,000 | 1,400,000 | 4,700,000 | 1,500,000 |

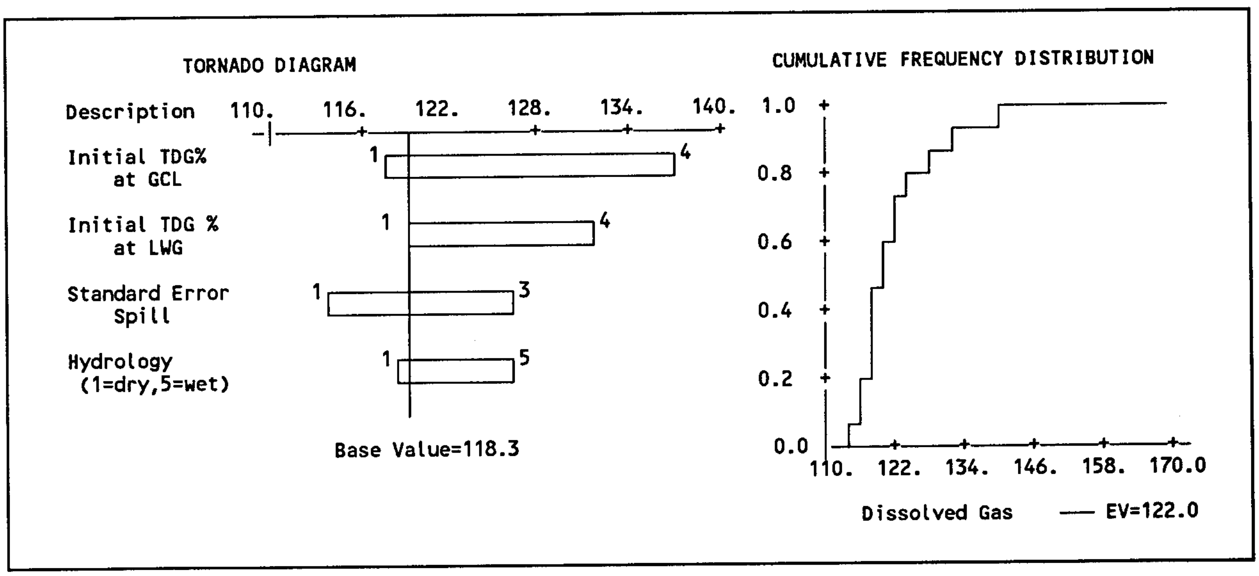


*Figure 1. Dissolved gas tornado diagram and cumulative probability distribution*

## Table 2
## Comparison Based on Water Temperature—Individual Years

| | Runoff Conditions | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOW 1929 | | | .... MEDIUM LOW .... 1962 | | | 1973 | | | MED.HIGH 1959 | | | HIGH 1974 | | |
| NO | ALT | EXC | GR | ALT | EXC | GR | ALT | EXC | GR | ALT | EXC | GR | ALT | EXC | GR |
| 1 | 5b | 1266 | 1 | 5b | 1266 | 1 | 5b | 1284 | 1 | 5b | 1282 | 1 | 5b | 1305 | 1 |
| 2 | 6c | 1282 | 1 | 6d | 1340 | 2 | 1b | 1313 | 2 | 6d | 1305 | 2 | 4a3 | 1356 | 2 |
| 3 | 6a | 1290 | 1 | 4b3 | 1341 | 2 | 6c | 1314 | 2 | 6b | 1308 | 2 | 1a | 1360 | 2 |
| 4 | 4b1 | 1309 | 1 | 4b1 | 1342 | 2 | 6a | 1320 | 2 | 6a | 1310 | 2 | 7a | 1368 | 2 |
| 5 | 4b3 | 1309 | 1 | 6c | 1345 | 2 | 4b1 | 1328 | 2 | 6c | 1310 | 2 | 1b | 1374 | 2 |
| 6 | 5a | 1314 | 2 | 4c | 1348 | 2 | 4b3 | 1328 | 2 | 1b | 1312 | 2 | 3b | 1379 | 2 |
| 7 | 6d | 1315 | 2 | 6b | 1348 | 2 | 6d | 1339 | 2 | 4a3 | 1314 | 2 | 3a | 1382 | 2 |
| 8 | 2a | 1316 | 2 | 4a1 | 1350 | 2 | 5a | 1345 | 2 | 1a | 1316 | 2 | 6c | 1386 | 3 |
| 9 | 2b | 1316 | 2 | 4a3 | 1350 | 2 | 6b | 1349 | 2 | 4a1 | 1316 | 2 | 6d | 1386 | 3 |
| 10 | 2c | 1317 | 2 | 6a | 1350 | 2 | 1a | 1354 | 3 | 4c | 1316 | 2 | 4b3 | 1387 | 3 |
| 11 | 4a1 | 1320 | 2 | 2b | 1353 | 2 | 4a1 | 1356 | 3 | 4b3 | 1317 | 2 | 6a | 1388 | 3 |
| 12 | 4a3 | 1320 | 2 | 5a | 1356 | 2 | 4a3 | 1356 | 3 | 4b1 | 1319 | 2 | 2a | 1390 | 3 |
| 13 | 6b | 1323 | 2 | 3a | 1358 | 2 | 2b | 1364 | 3 | 3a | 1324 | 3 | 7b | 1390 | 3 |
| 14 | 4c | 1324 | 2 | 7b | 1360 | 2 | 2a | 1366 | 3 | 5a | 1327 | 3 | 2c | 1391 | 3 |
| 15 | 3a | 1348 | 3 | 2a | 1363 | 2 | 4c | 1366 | 3 | 7b | 1330 | 3 | 7c | 1391 | 3 |
| 16 | 1b | 1353 | 3 | 7c | 1363 | 2 | 2c | 1368 | 3 | 2a | 1334 | 3 | 6b | 1392 | 3 |
| 17 | 7a | 1373 | 3 | 2c | 1365 | 2 | 3a | 1395 | 4 | 2b | 1337 | 3 | 4c | 1393 | 3 |
| 18 | 3b | 1376 | 3 | 1a | 1366 | 2 | 7c | 1397 | 4 | 2c | 1337 | 3 | 4b1 | 1395 | 3 |
| 19 | 1a | 1380 | 3 | 1b | 1366 | 2 | 7b | 1404 | 4 | 3b | 1352 | 4 | 2b | 1398 | 3 |
| 20 | 7b | 1434 | 4 | 7a | 1376 | 3 | 3b | 1422 | 4 | 7c | 1360 | 4 | 4a1 | 1400 | 3 |
| 21 | 7c | 1446 | 4 | 3b | 1385 | 3 | 7a | 1366 | 4 | 7a | 1366 | 4 | 5a | 1416 | 4 |

Note: NO = Number; ALT = alternatives; EXC = Number of days exceeding the threshold at all locations; GR = grouping (rank).

## Table 3
## Comparison Based On Water Temperature—All 5 Years Combined

| | | Ranking for Individual Years | | | | | | |
|---|---|---|---|---|---|---|---|---|
| NO | ALT | LOW 1929 | MD.LO 1962 | MD.LO 1973 | MD.HI 1959 | HI 1974 | SUM FOR ALL 6 YEARS | INDEX O OVERALL IMPACT |
| 1 | 1a | 3 | 2 | 3 | 2 | 2 | 12 | 0.2 |
| 2 | 1b | 3 | 2 | 2 | 2 | 2 | 11 | 0.5 |
| 3 | 2a | 2 | 2 | 3 | 3 | 3 | 13 | 0.0 |
| 4 | 2b | 2 | 2 | 3 | 3 | 3 | 13 | 0.0 |
| 5 | 2c | 2 | 2 | 3 | 3 | 3 | 13 | 0.0 |
| 6 | 3a | 3 | 2 | 4 | 3 | 2 | 14 | -0.3 |
| 7 | 3b | 3 | 3 | 4 | 4 | 2 | 16 | -0.8 |
| 8 | 4a1 | 2 | 2 | 3 | 2 | 4 | 13 | 0.0 |
| 9 | 4a3 | 2 | 2 | 3 | 2 | 2 | 11 | 0.5 |
| 10 | 4b1 | 1 | 2 | 2 | 2 | 3 | 10 | 0.8 |
| 11 | 4b3 | 1 | 2 | 2 | 2 | 3 | 10 | 0.8 |
| 12 | 4c | 2 | 2 | 3 | 2 | 3 | 12 | 0.2 |
| 13 | 5a | 2 | 2 | 2 | 3 | 4 | 13 | 0.0 |
| 14 | 5b | 1 | 1 | 1 | 1 | 1 | 5 | 2.0 |
| 15 | 6a | 1 | 2 | 2 | 2 | 3 | 10 | 0.8 |
| 16 | 6b | 2 | 2 | 2 | 2 | 3 | 11 | 0.5 |
| 17 | 6c | 1 | 2 | 2 | 2 | 3 | 10 | 0.8 |
| 18 | 6d | 2 | 2 | 2 | 2 | 3 | 11 | 0.5 |
| 19 | 7a | 3 | 3 | 4 | 4 | 2 | 16 | -0.8 |
| 20 | 7b | 4 | 2 | 4 | 3 | 3 | 16 | -0.8 |
| 21 | 7c | 4 | 2 | 4 | 4 | 3 | 17 | -1.0 |

## Trade-Off Summary

The final comparison of alternatives for water temperature, total dissolved gas saturation, and sediment transport is summarized in Table 4. Drawdown alternatives are indicated with an asterisk. The column labeled "Overall Ranking" was intentionally left blank, as no composite ranking based on all three parameters was assigned at this stage of the analysis. Such a ranking would have to be based on direct as well as indirect impacts. Graphic display of the summary trade-off results is provided in Figure 2.

**Table 4**
**Summary Comparison Based on Overall Performance Indices**

| N. | ALT | | .. Indices of Overall Impact .. WATER TEMP. | DISSOLV. GAS | SEDIMENT LOAD | OVERALL RANKING | INTENDED OBJECTIVES OF THE ALTERNATIVES |
|---|---|---|---|---|---|---|---|
| 1 | 1a | | 0.2 | 0.2 | 0 | ? | 1983-91 operations |
| 2 | 1b | | 0.5 | 0.2 | 0 | | optimize power |
| 3 | 2a | | 0.0 | 0.1 | 0 | | 1992-93 operations, Columbia/Snake fish |
| 4 | 2b | | 0.0 | 0.1 | 0 | | ditto,+ Libby Sturgeon |
| 5 | 2c | | 0.0 | 0.0 | 0 | | 1993 operations, Columbia/Snake fish |
| 6 | 3a | | -0.3 | -0.1 | 0 | | meet flow target for fish |
| 7 | 3b | | -0.8 | -0.6 | 0 | | ditto+ upper Snake water |
| 8 | 4a1 | | 0.0 | -0.2 | 0 | | recreation, resident fish, wildlife |
| 9 | 4a3 | | 0.5 | -0.5 | 0 | | ditto+ Anadromous fish |
| 10 | 4b1 | | 0.8 | -0.3 | 0 | | ditto+ Anadromous.fish |
| 11 | 4b3 | | 0.8 | -0.6 | 0 | | ditto+ Anadromous fish |
| 12 | 4c | | 0.2 | -0.5 | 0 | | ditto+ Anadromous fish |
| 13 | 5a | * | 0.0 | 1.5 | -1.6 | | Anadromous fish (2 months drawdown) |
| 14 | 5b | * | 2.0 | 1.6 | -2.0 | | Anadromous fish (4.5 months drawdown) |
| 15 | 6a | * | 0.8 | 0.3 | -1.0 | | Anadromous fish (2 months, 4 reservoirs) |
| 16 | 6b | * | 0.5 | 0.4 | -1.3 | | Anadromous fish (4.5 months, 4 reservoirs) |
| 17 | 6c | * | 0.8 | 0.1 | -0.3 | | Anadromous fish (2 months, Lower Granite only) |
| 18 | 6d | * | 0.5 | 0.1 | -0.6 | | Anadromous fish (4.5 months, Lower Granite) |
| 19 | 7a | * | -0.8 | -1.3 | -0.3 | | Anadromous fish (flow targets) |
| 20 | 7b | | -0.8 | -0.0 | 0 | | Anadromous fish |
| 21 | 7c | | -1.0 | -0.2 | 0 | | Anadromous fish |

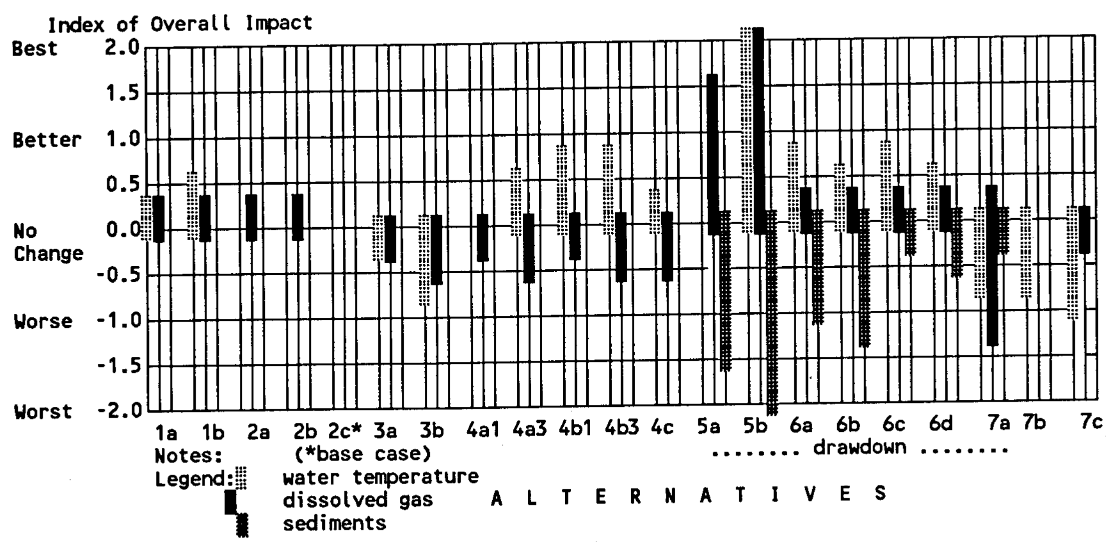


*Figure 2. Comparison summary for water temperature, total dissolved gas, and sediments transport*

## Conclusions

SOR requires assessment and comparison of 21 alternatives based on predicted impacts on three water quality parameters. This task was accomplished using a numerical rating procedure based on performance indices defined as number of days HEC-5Q, HEC-6, and GASSPILL models-predicted impacts exceed selected threshold values. The rating further led to the determination of a relative ranking system that relates the impacts of alternatives to those of the current operations used as base case. The resulting trade-off summary table has proven to be a practical and objective basis for decision makers and others to rank and select the recommended alternative(s). From the analysis that has been performed, more than one alternative will be required to provide optimum water quality conditions in the Columbia River basin. Even within a given alternative, system regulation during extreme flow years may need to be different from that used in an average year.

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# Drawdown of Lower Snake River Reservoirs: Sediment Erosion and Resulting Water Column Impacts

*by*

*Thomas D. Miller,*[1] *Thomas H. Martin,*[2] *and Lester L. Cunningham*[1]

## Abstract

*Drawdown and operation of the four run-of-the-river reservoirs on the Lower Snake River below normal operating elevations is proposed as a means to improve salmon smolt outmigration conditions. Reduced cross-sectional areas resulting from lower pool elevations may reduce downstream travel time of juvenile fish because of increased velocities, potentially increasing their survival. This measure would, however, increase the sediment load because of exposed bank erosion and scouring of sediments deposited during normal operations, potentially impacting outmigrating smolts.*

*The Corps of Engineers, Bureau of Reclamation, and Bonneville Power Administration are currently reviewing Lower Snake River drawdown as an alternative strategy in the Columbia River System Operation Review (SOR). Various pool elevations have been evaluated, including full-pool as base case, drawdown to 33 ft below normal, and drawdown to preimpoundment river level. The sediment loading estimation process required the integration of three theoretical computer models and a Geographic Information System (GIS) to predict sediment inputs from all sources and to track the water column and sedimentation effects downstream to Bonneville Dam. The Corps of Engineers Hydrologic Engineering Center's HEC-6 Sediment Transport Model provided streambed scour inputs from Lower Granite Reservoir. A spreadsheet-based Bank Erosion Model predicted sediment loading from the exposed banks by erosion processes including surface erosion of exposed mudflats, wave erosion, slumping and mass wasting, and tributary delta incision. Scour and bank erosion loads from the other three Lower Snake reservoirs were extrapolated from the Lower Granite results based on the sediment deposition history of each pool. The recently enhanced version of the HEC-5Q Reservoir Water Quality Model used daily inputs from HEC-6 and the Bank Erosion Model to simulate estimated water column concentrations and transport.*

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2 Enserch Environmental, Inc., Bellevue, WA.

*Suspended sediment concentration maxima at Lower Granite Dam for the base case, 33 ft, and natural river level drawdown simulations were approximately 40, 80, and 3,000 mg/L, respectively. It was predicted that the majority of sediment transported from lowered Snake River pools was deposited in McNary Reservoir, immediately downstream from the confluence of the Snake and Columbia rivers. Daily results of lead, DDT series, silt, ammonia, and phytoplankton are being used in parameter threshold exceedence frequency analyses. Direct comparison of percentage of days that a parameter exceeds the selected threshold for each alternative and flow regime results will result in ranking of alternatives. Predictably, alternative comparisons show that sediment and associated contaminant transport was directly related to depth and duration of drawdown and to the number of reservoirs involved.*

# Smithland Locks and Dam—A Dredging Case Study

*by*
*Gordon R. Lance*[1]

## Introduction

The purpose of this paper is to explain how the construction of a new navigation project on the Ohio River inadvertently created the worst dredging problem in the Louisville Engineer District. This is in spite of some careful planning to avoid this problem.

## Smithland Locks and Dam

The Smithland project retained upper pool and went into service in 1981. This project is the newest in a series of replacement locks and dams on the Ohio River. Smithland replaced two antiquated manually operated wicket dams that date back to the 1920s. Those projects had been rendered obsolete by the increase in the size of the tow fleets operating on the Ohio and the power of the newer towboats. The new dam has a maximum lift of 22 ft, which classifies it as a "high lift" lock in Ohio River parlance. The project has two locks, each 1,200 ft long by 110 ft wide, and is the only such "twin lock" project in the world. The dam consists of 11 tainter gates located adjacent to the locks and a 1,570-ft-long fixed weir. The tainter gates are each 110 ft wide by 36 ft high. River traffic normally passes through the locks, but during periods of extreme high water, tows can pass over the fixed weir.

The project is located on the Ohio River 918 miles below Pittsburgh and 63 miles above the mouth of the river at Cairo, IL. The dam is only 2 miles upstream of the mouth of the Cumberland River and 16 miles above the mouth of the Tennessee River at Paducah, KY.

A general location map is shown on Figure 1. Figure 2 is a sketch of the project showing some of the features of the project.

The river was changed significantly by the construction of Smithland. Prior to Smithland Locks and Dam, there was an island upstream of Cumberland Island near the Illinois shoreline known as Dog Island. The main navigation channel was down the left descending bank of the Ohio and around the left side of Cumberland Island through what is known as the Kentucky chute. High-water traffic had the option of going around either side of Cumberland Island. In general, this traffic preferred the right side of the island, known as the Illinois chute. During the design process, someone got the bright idea of constructing the locks on Dog Island, thereby saving considerable money on in-river cofferdams. For this plan to work, however, it was necessary to abandon the existing navigation channel. All traffic would be shifted to the right descending bank of the river and the Illinois chute would be used below the dam. The Kentucky chute would continue to be used for access to the Cumberland River. Preconstruction conditions are shown on Figure 3.

The design team was aware of the tendency of the sand bottom of the Ohio River to move from time to time. Since the project involved shifting the navigation channel across the river, special caution flags were raised. Accordingly, provisions were made in the model study program to investigate potential reshaping of the riverbed in response to the new project. It was clear that the project plan should include whatever features were necessary to keep the new channel open, thereby minimizing dredging requirements.

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[1] U.S. Army Engineer Division, Ohio River; Cincinnati, OH.

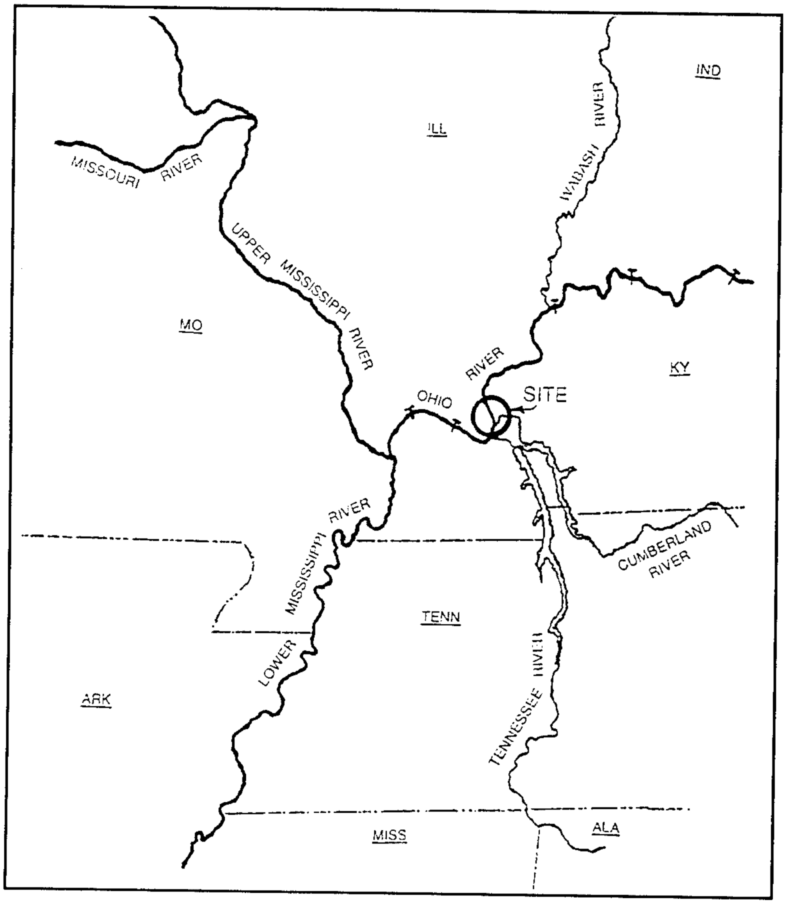


*Figure 1. Location of project*

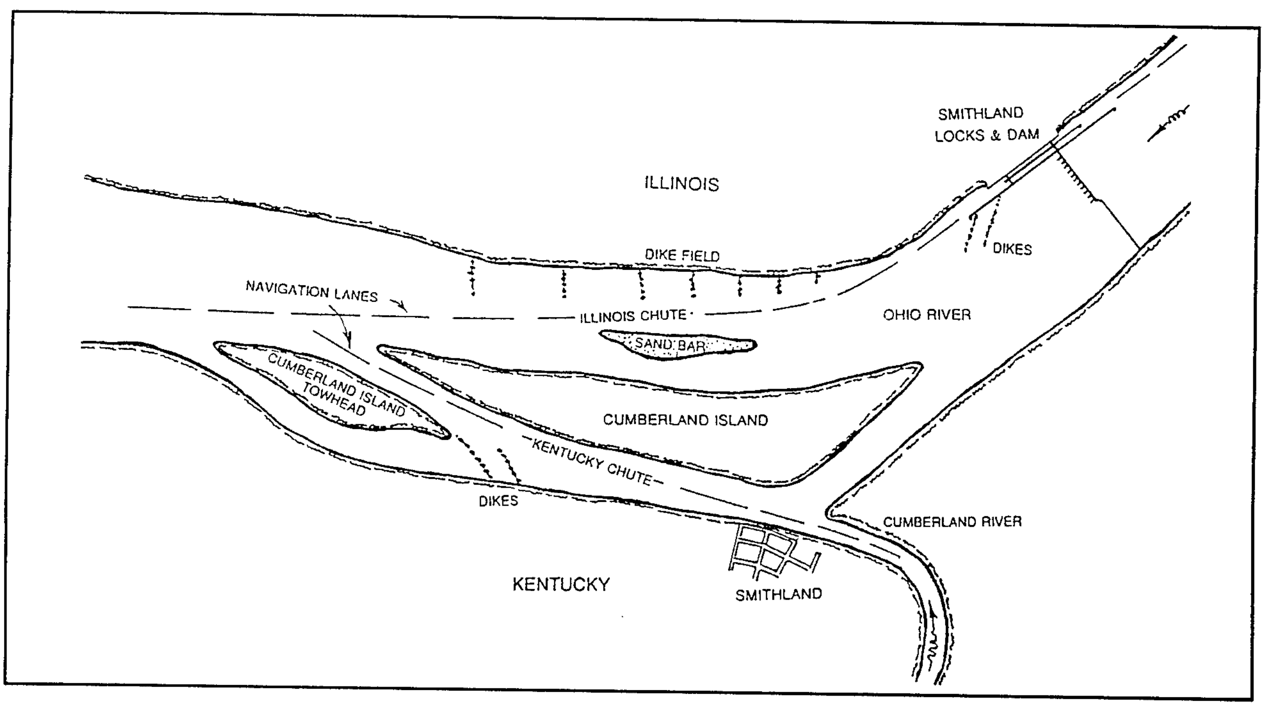


*Figure 2. Smithland Locks and Dam*

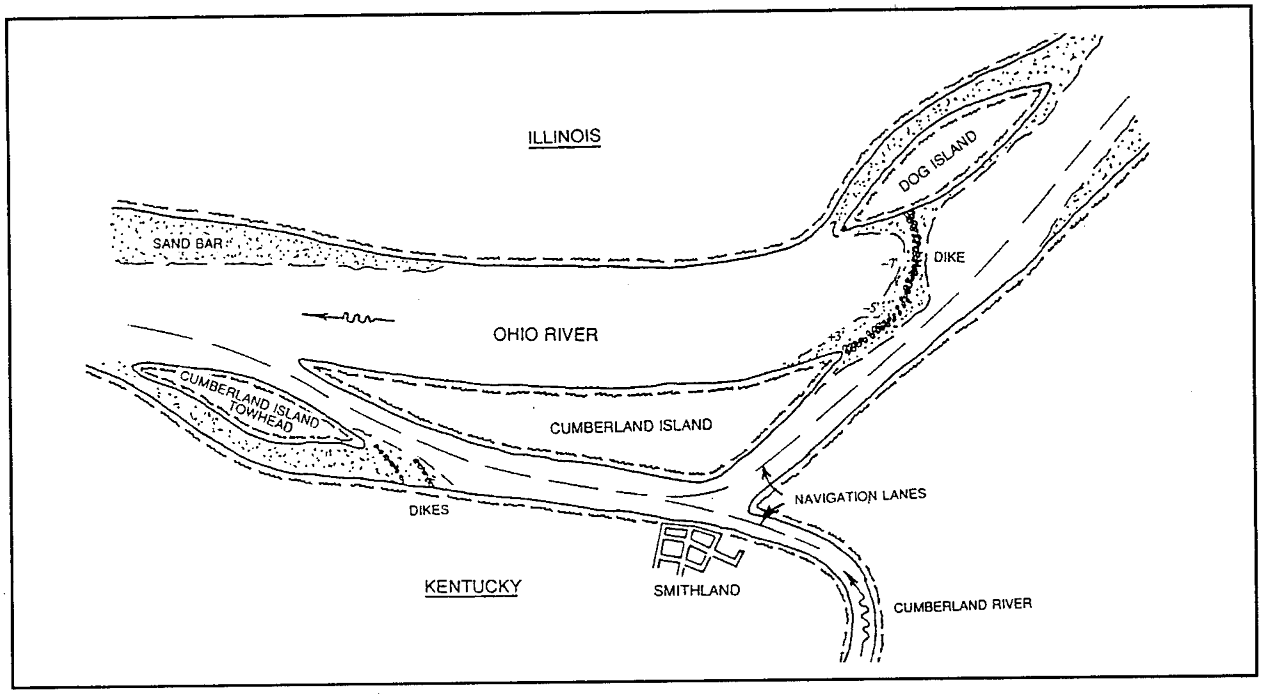


*Figure 3. Pre-Smithland conditions*

## Model Study

Like all Ohio River navigation projects, a physical model study of flow and navigation conditions was commissioned at the the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, MS. The model covered the Ohio River from River Mile 916.5 to 925, and the lower 4 miles of the Cumberland River. The model had a scale of 1:150 and was molded out of neat concrete. As is normal in these types of studies, several iterations of lock and dam configurations were evaluated, along with additional design assistance with the dam cofferdams and with the closure section of the fixed weir. The model study was eventually published by WES as TR HL-83-19 (Franco and Pokrefke 1983).

Fixed-bed models of this type can provide only a limited amount of useful information about the movement of bed material and can only infer how the riverbed will reshape itself in response to a structure in the channel. One can trace bottom currents with dye and identify eddy-type depositional areas with neutrally buoyant particles, but no useful information about bottom scour can be provided. Realizing this limitation and knowing of the concern about the new navigation channel, WES converted the model to a moveable bed model by replacing the concrete bed of the river with a thick bed of coal. The hydraulic gradient in the model was steepened to get the coal to behave like the prototype riverbed. A yearlong representative hydrograph was selected for design purposes, and a number of different features were evaluated. While the bed was converted to a moveable condition, the streambanks and all islands in the model retained their concrete skins.

Gleaning useful information from moveable bed models is as much an art as it is a science. Uncertainties and localized differences about bottom gradations and the energy required to mobilize those materials exist. Representation of the multiple gradations of bed materials with a single material obviously introduces other uncertainties. Test cycles tend to be long, so the number of plans that can be evaluated is also limited. With all these reservations and limitations, this type of model represents the state-of-the-art study tool with respect to sand bed river channels.

Considerable time and effort were devoted to this phase of the model study, and at least 14 different plans were evaluated. The study objective was to develop a "self cleaning" channel down the Illinois chute, a concept sketched on Figure 4. Most of the tainter gate discharge was to be down the Illinois chute. This would maintain moderate scouring velocities necessary to prevent deposition in the chute. The final plan consisted of two dikes attached to the river wall of the lock, and seven additional dikes in the upper portion of the Illinois chute. The chute dikes were included to maintain necessary chute velocities. The two dikes attached to the Kentucky shore near the head of Cumberland Island Towhead had been in place for some time and were not a part of this project. The two dikes off the lower lock wall were designed to shift the eddy deposits away from the immediate lower lock approach.

There was an old dike in the river that once had connected Dog and Cumberland islands. This dike was known locally as "Shreve's Dike" because it was attributed to Captain Henry Shreve, who had served as the Superintendent of Western Waters in the 1820s and 1830s. All of the model tests conducted at WES were based on the removal of this old dike. A note requiring removal of this dike was included in the project plans.

## The Problem

After a few years of operation, it became apparent that something was seriously wrong at Smithland, specifically in the lower approach to the lock and all down the Illinois chute. Very high levels of dredging were required in this area. For the first few years, this problem was attributed to initial adjustment of the system; but by the end of the decade, it was obvious that the river in the project area was not preforming as anticipated. Not only were heavy sand deposits occurring in the navigation channel, but the head of Cumberland Island was retreating at an alarming rate. The owner of the island lived directly across the river in the community of Smithland, Kentucky, and he was not pleased with what he was seeing. In fact, he later sued the Government for adverse possession of his property and won.

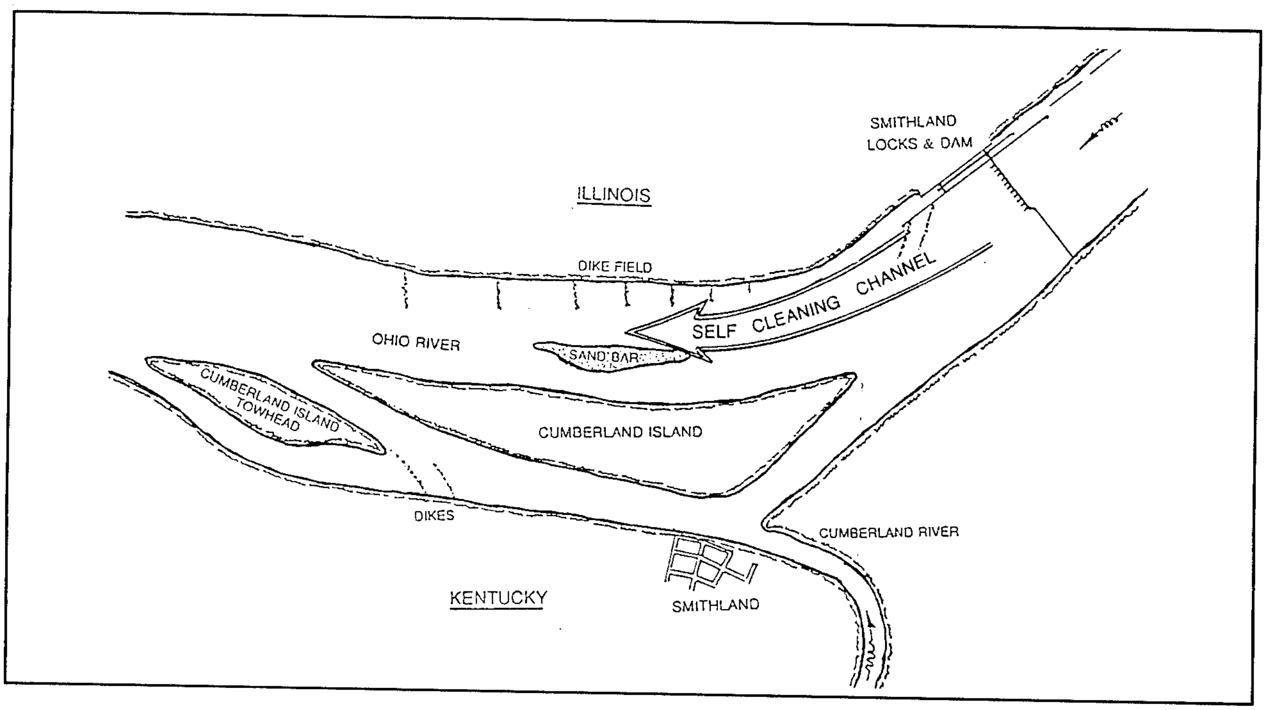


*Figure 4. Self-cleaning channel*

The results of an inspection of the area in 1990 by the writer and others are shown on Figure 5. The head of Cumberland Island was actively failing, with slabs of soil falling into the water every 20 min or so. The failing face of the island was vertical, standing some 15 ft above the water surface. A very strong current was sweeping across the face of the island and flowing down the Kentucky chute. Soundings taken adjacent to the island showed 10 to 14 ft of water immediately adjacent to the failure surface.

The most ominous aspect of this situation was the apparent tendency of the tainter gate discharge to cut across the head of the island. If that current ever became the predominate path for the gate discharge, keeping the Illinois chute open would become very costly. The retreat of the head of the island was complicating this matter as the "channel" across the island was continually expanding. The locks cannot be approached from the Kentucky chute.

It was obvious that something had to be done. The first step was to find out what was causing the problem and then develop the lowest cost solution to the problem. The study process involved consulting the historical record on the area, taking soundings, and consulting WES. Mr. Tom Pokrefke of the Hydraulics Laboratory at WES, one of the authors of the WES report, was very helpful with this problem.

## Historical Record

It turned out that the Louisville District had accumulated a wealth of historical information about this reach of the river as part of the Smithland design process. Most of the data in the District's files had been compiled by Mr. Leland Johnson, a Corps historian in Washington. Mr. Johnson's report had been commissioned to estimate how much stone was involved in the construction of Shreve's dike. The report contains a series of old maps and cost estimates and tells an interesting story of navigation in this area dating well back to the beginning of the steamboat era on the Ohio River.[1]

The oldest useful map of the area was prepared in 1832 by a Corps of Engineers officer named Captain Richard Delanfield, operating under the direction of Henry Shreve. The main, or "low water," channel of the Ohio River was through the Illinois chute, and the head of Cumberland Island was connected to the Kentucky shore by a massive sandbar. The town of Smithland (which was shown about the same size it is today) is clearly sited on the Cumberland River. According to Johnson's report, traffic on the Cumberland River was very limited, while Ohio River traffic was beginning to boom. The general situation shown on Captain Delanfield's map is sketched on Figure 6.

Apparently, people in Smithland desperately wanted to be located on the busy Ohio River rather than on a backwater river like the Cumberland. This would allow the community to grow and prosper. In order to do this, however, it would be necessary to remove the sandbar at the head of Cumberland Island and relocate all Ohio River traffic to the Smithland waterfront. Someone prevailed on Congress to include a special project to accomplish that objective in an 1831 equivalent of a rivers and harbors act. A stone dam, to be known as Cumberland Dam, was authorized for construction across the upper end of the Illinois chute. Funding was provided and the dam was built by the Corps of Engineers under the general supervision of Captain Shreve. The dam had to be enlarged and extended several times before it finally shifted the low-water channel to the Smithland waterfront. One of the military officers that worked on this project in the late 1830s was a young Virginian named Robert E. Lee. A sketch of the apparent original position of the dam is shown on Figure 7.

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[1] Unpublished Memorandum, 1981, Leland Johnson, "History of the Construction of Cumberland Dam, 1831-79."

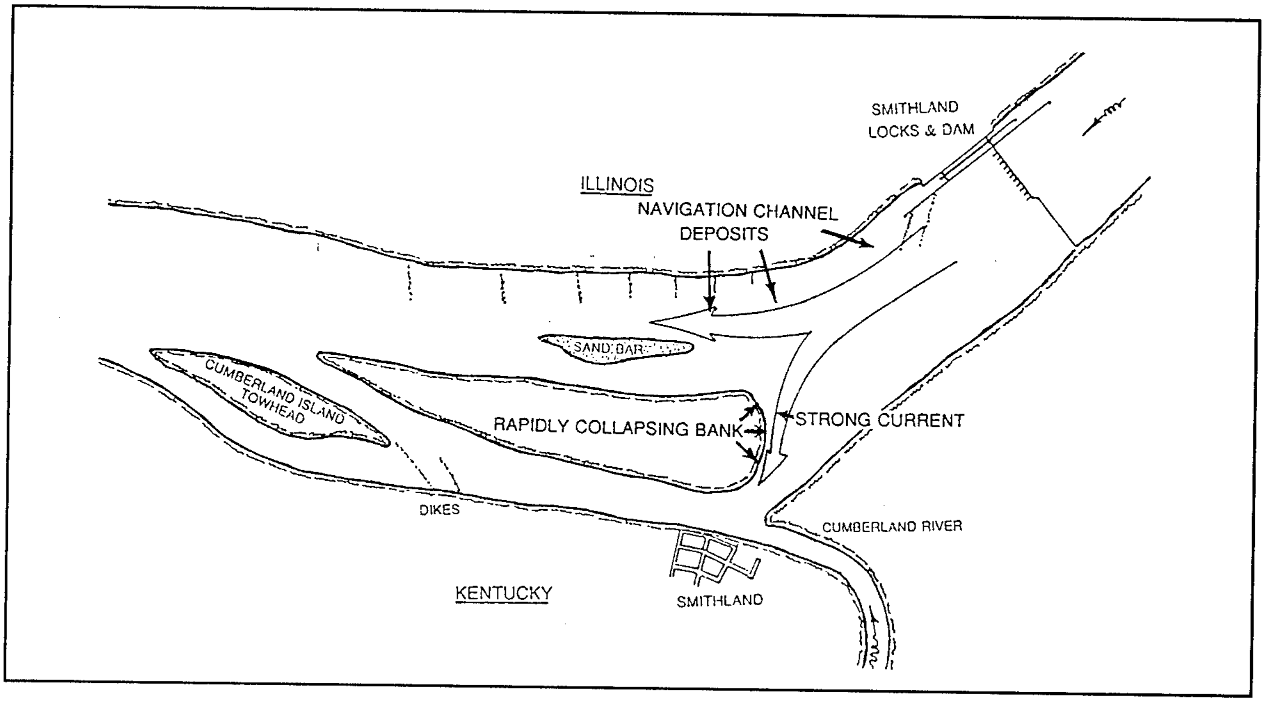


*Figure 5. Conditions in 1990*

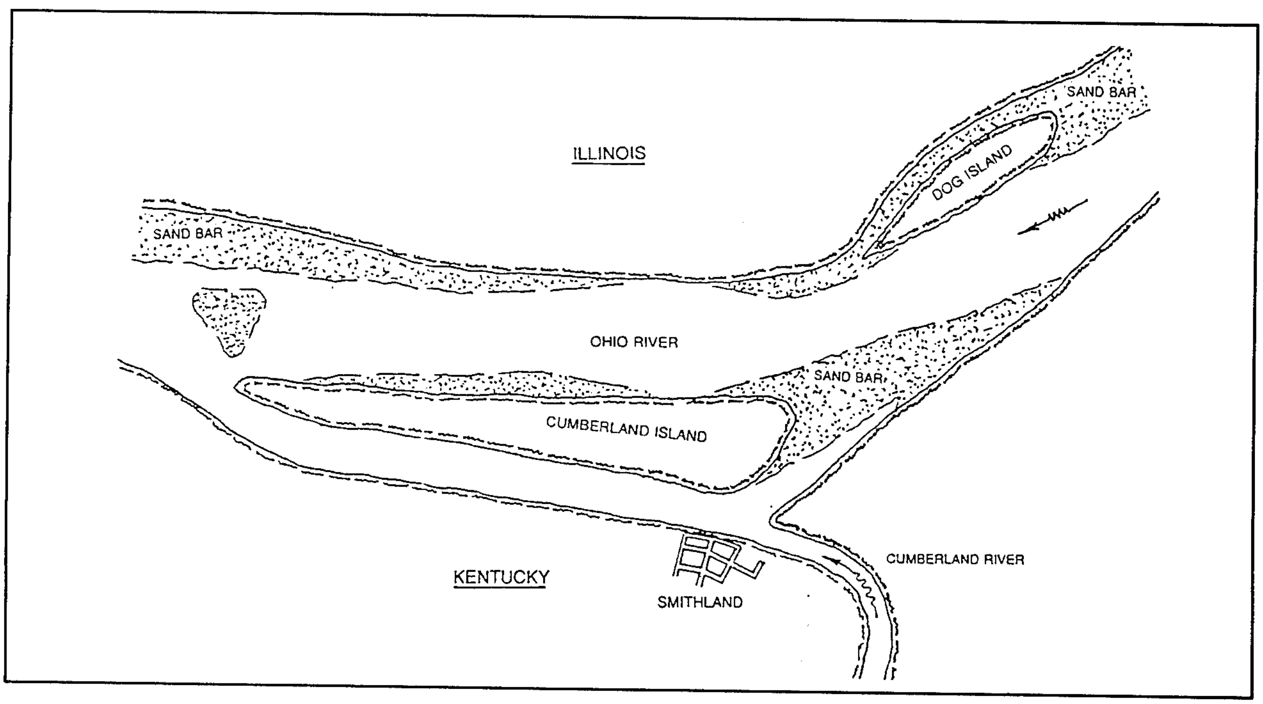


*Figure 6. Conditions in 1832*

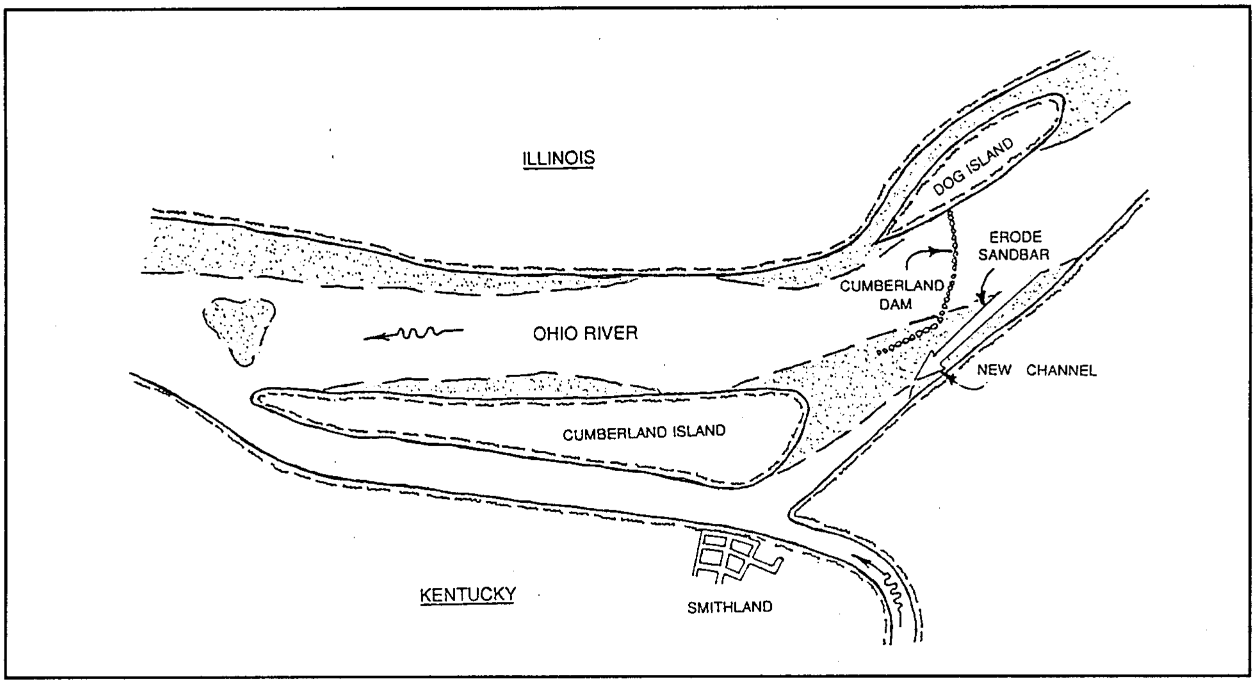


*Figure 7. Cumberland Dam (Circa 1845)*

Although the dam finally did perform as planned, the town of Smithland never did grow into another St. Louis or Pittsburgh. Ohio River steamboat pilots did not like using the Kentucky chute because of the extra maneuvering required. This situation became worse after the practice of pushing barges developed. Whenever the water was high enough, pilots reverted to the Illinois chute, and a number of accidents in the 19th century were attributed to attempts to run the dam with insufficient water.

The situation had been stabilized for a long period of time when the construction of the Smithland Locks was started (see Figure 3). Cumberland Dam had been buried in a massive sandbar that now connected Dog Island with Cumberland Island. The low-water pool had been raised and stabilized in 1930 by the construction of Lock and Dam 52, some 18 miles downstream. Low-water traffic was using the Kentucky chute, but continued to run the Illinois chute whenever the water was high enough. The head of Cumberland Island had grown in an upstream direction to form a point. This growth caused the island to meet a lateral extension of the dam that had been added to the left side of the dam to prevent flanking channels from developing in the sandbar. Two dikes at the lower end of the Kentucky chute were doing a good job of keeping the lower end of that chute open. These dikes were constructed in 1888, but had been first proposed by Captain Lee in 1839. The community of Smithland was the same size it had always been.

## Soundings

It is the practice in the Louisville District to take soundings only in that part of the river within the navigation channel. In this case, however, soundings of most of the river below the dam and above Cumberland Island were made early in 1990. The bottom configuration found in that survey is shown in Figure 8. It was obvious that only a limited portion of Cumberland Dam had been removed during the construction of Smithland Locks. A short section of Cumberland Dam immediately off the nose of Dike No. 1 had been completely removed. The exposed soft bottom in that gap had eroded. About 500 ft

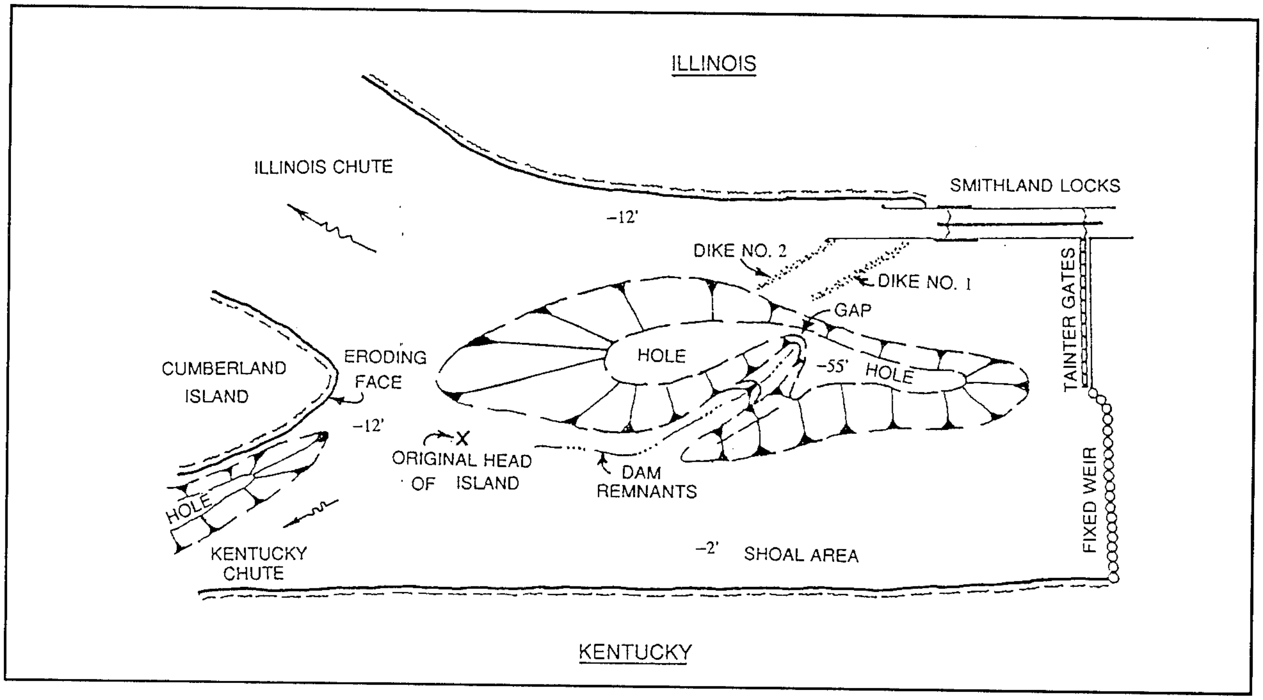


*Figure 8. Soundings taken in 1990*

of Cumberland Dam adjacent to that gap had been decapitated to a fairly consistent elevation, about 27 ft below lower pool. The left abutment of the dam was untouched, as was the lateral extension of the dam. An ominous deep channel was forming immediately off the rapidly failing head of the Cumberland Island. This deep channel and the strong currents in the area obviously were preventing stabilization of the failing bank.

According to oldtimers familiar with the construction of the Smithland project, work on the dike was terminated because of funding limitations and other contract problems. The contractor had experienced a great deal of difficulty locating the dam because of the massive sandbar that had been formed in the area. The sand from the bar would collapse into any excavation opened by the contractor's clamshell.

The 1990 soundings show that this massive sandbar was now completely gone, and the dam was now easy to locate.

## Consultations with WES

Personnel at WES are never pleased to find that a project that has been through such an extensive modeling process is not performing properly. After some review, probable reasons for this unacceptable performance became apparent. The most obvious problem is that Cumberland Dam had not been removed as planned. WES had not modeled the situation that might develop for such a condition. The second reason was a little more subtle. The model had been evaluated with a moveable bed, but with concrete banks and islands. The process of bank failure and retreat had not been included in the WES studies. As a matter of note, no existing physical or computational models are available to study the most common type of riverbank failure found on the Ohio, which is failure by internal erosion.

While the model had not predicted prototype behavior, it remained a key document in dealing with the problem.

## Remedial Construction

The plan developed to fix this problem was pursued as a construction deficiency. That plan is shown on Figure 9. The plan consisted of two phases. Phase 1 was to be first pursued; if that did not fix the problem, then Phase 2 would be necessary. Phase 1 consisted of removal of all of Cumberland Dam except the extension off the left abutment. All of the stone taken from the dam would be used to form a "V" shaped, or "chevron" dike outlining the old pointed upstream nose of Cumberland Island. The minimum length of the "legs" on the dike was to be 600 ft. If there was insufficient stone in the dike, then new riprap was to be purchased. If extra stone were found in the dam, then the Illinois leg of the chevron dike was to be extended. If all went well, a sandbar would develop between the chevron dike and the head of the island. This sandbar should stop the retreat of the island by reducing the crosscurrent and allowing failed bank materials to accumulate and flatten the slope. The tainter gate discharge would then be firmly directed down the Illinois chute.

If Phase 1 was insufficient to correct the condition, then Phase 2 would be pursued. This element consisted of extending the right side of the chevron dike down to Cumberland Island. This would definitely "harden up" the left side of the chute and positively redirect the current down the right side of the island.

It is believed that the removal of Cumberland Dam and the redirection of flow down the Illinois chute will substantially reduce the frequency and magnitude of necessary dredging, with its environmental consequences, for the following reasons. First, the plan tends to be more closely aligned with the "natural" bedforms in the river as shown in the 1832 map. The second reason for optimism is that the plan would restore the river to the conditions analyzed in the model, as the stone dikes would mimic the concrete islands in the model.

## Results

Only partial results of this effort are known at this time. Phase 1 was carried out

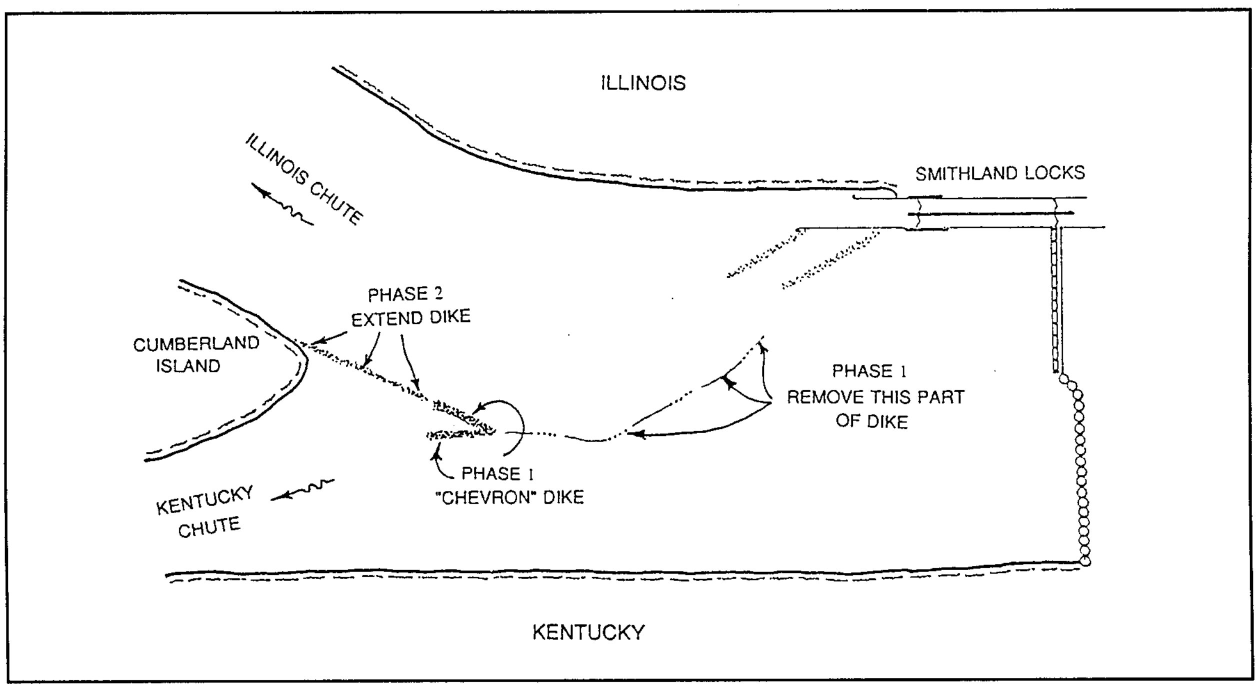


*Figure 9. Proposed remedial project*

in 1992. There was sufficient stone excavated from the dike to provide for both 600-ft legs of the chevron, and to extend the Illinois leg by 500 ft. After this phase was completed, a strong current remained around the lower end of the new chevron dike, and the retreat of the head of the island continued. The dike apparently was not long enough to extend into the deep-water channel forming upstream of the island. Since Phase 1 proved to be ineffective by itself, Phase 2 was initiated as a separate contract. That work is now underway. In an additional attempt to restore the head of the island (and to also find a place to deposit dredged material), the District is now depositing dredged sand from the lower approach area behind the new dike.

## Lessons Learned

Probably the most important lesson to be learned from this effort is to expect the unexpected when dealing with shifting riverbeds. The District was correct to concern itself with the consequences of a major shift in river channel, and the moveable bed model was (and remains) the evaluation tool of choice for such matters. These models are imperfect, so their results must be used with caution. Accurate model predictions of prototype behavior can be very sensitive to what might appear as minor changes in the project. Sometimes the use of fixed model boundaries can provide misleading guidance. Special care and judgement must always be exercised in applying model results to prototype situations. Even if things do not go as predicted in a model, that study can provide invaluable insight to an emerging problem. Also, careful monitoring of new installations is necessary to nip emerging situations in the bud.

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# Caesar Creek Lake Water Quality and Modeling Study

*by*
*Joseph A. Bohannon*[1]

## Introduction

The Water Quality Group, U.S. Army Engineer District, Louisville, has made a long-term commitment to water quality modeling. The model of choice is CE-QUAL-W2. The Water Quality Group plans to model at least one reservoir per year until all 20 projects of the Louisville District have been modeled. The next modeling project will be Taylorsville Lake in Taylorsville, KY, for which considerable data have already been collected from previous studies. In addition, sample collection will begin in April of this year at Monroe Lake in Bloomington, IN. Modeling for this project should begin early next year.

## Development of CE-QUAL-W2

CE-QUAL-W2 has been under continuous development since 1975. The early versions of this model were known as LARM (Laterally Averaged Reservoir Model). The initial application of LARM was on a reservoir with no branches. Subsequent modifications to allow for multiple branches and the ability to handle boundary conditions for estuaries resulted in the GLVHT (Generalized Longitudinal-Vertical Hydrodynamics and Transport) model. GLVHT has been successfully used to simulate temperature distributions and circulation in water bodies and has been applied to a variety of aquatic systems. The addition of water quality algorithms by the Water Quality Modeling Group at the U.S. Army Engineer Waterways Experiment Station (WES) resulted in version 1.0 of CE-QUAL-W2.

## Background on CE-QUAL-W2

CE-QUAL-W2 is a numerical, two-dimensional, laterally averaged hydrodynamic and water quality model. It describes vertical and longitudinal distributions of thermal energy and selected biological and chemical materials in a water body through time. The primary reason for selecting this model is its ability to define water quality gradients in two dimensions. In most Corps reservoirs, significant variations in water quality conditions occur along both longitudinal and vertical axes. Although developed for reservoirs, another asset of the model is that it can be applied to other systems, such as lakes, rivers, and estuaries.

The model is capable of simulating the dynamics of up to 20 water quality constituents in addition to temperature, density, and velocity. The model calculates water volumes, surface elevations, densities, vertical and longitudinal velocities, temperatures, and constituent concentrations as well as downstream release concentrations. Required input data include initial conditions, reservoir geometry, physical coefficients, biological and chemical reaction rates, and time sequences of hydrometeorological and inflowing constituent loadings.

Constituents are arranged in four levels of complexity-conservative (noninteractive), interactive (oxygen-phytoplankton-nutrients), simulated pH and carbonate species, and simulated total iron. This allows for considerable flexibility in application of the model. The model simulates the interaction of physical

[1] U.S. Army Engineer District, Louisville; Louisville, KY.

factors (flow and temperature), chemical factors (nutrients), and an algal compartment. Many constituents are simulated primarily to include their effects upon other constituents. Essentially, the model deals with the major physical, chemical, and biological processes that occur within an impounded body of water. It is particularly applicable to reservoir projects that involve correlation of numerous parameters and considerable technical data.

## Time Requirements/Problems for First-Time Users

The application of CE-QUAL-W2 requires knowledge in the following areas:

- Hydrodynamics.
- Biology.
- Chemistry.
- Numerical methods.
- Computers and FORTRAN coding.
- Statistics.
- Data assembly and reconstruction.

Water quality modeling requires not only knowledge in these areas but experience in their integration. Application of the model for the first-time user is a complicated and time-consuming process. The modeling team needs to be an interdisciplinary group with knowledge in as many of the above-listed areas as possible. Also, involvement of several people on the team minimizes a drop in proficiency in the event a team member leaves or is transferred.

### Time Requirements for Model Runs

Yearly model runs require 1 to 2 hr based on the number of constituents turned on. Plotting and viewing requires another hour for a total time of 2 to 3 hr. The LOTUS graphing package proved inadequate for displaying model runs. At the recommendation of WES, AXUM software was purchased to expedite the graphing functions. However, there is a learning curve associated with using AXUM for the first time. Although initial set-up is time consuming, this graphics program makes processing and viewing of calibration runs much easier.

### Turnaround Time for Laboratory Samples

Optimum turnaround time on samples requiring laboratory analysis is 3 to 4 weeks. Delays in getting back results are usually due to inconsistencies between computerized test requests and labeling of samples turned in to the laboratory. Accurate and consistent coding of samples prevents problems in tracking down missing test results. Also, determine in advance what the detection limits are for various laboratory procedures. Otherwise, actual numerical values from laboratory analyses may not be reported because they are less than the detection limits preprogrammed into the computer.

### Bathymetry of Reservoir Basin

Setting up the bathymetry for the model requires detailed digitizing. The accuracy of the bathymetry is critical to the success of the model. The data points provided are utilized in determining the computational grid for the model. The grid consists of a series of vertical columns (segments) and horizontal rows (layers), with the number of cells equaling the number of segments times the number of rows. The basic parameters used in developing the grid are longitudinal spacing (delta x in meters) and vertical spacing (h in meters). Vertical spacing can vary from model to model; but once established, it remains constant throughout the reservoir. Horizontal spacing can vary with each branch of the reservoir. Each cell also has an associated average width.

Mapping for Caesar Creek was performed by the Survey and Mapping Section of the Louisville District. It was done from pertinent topographic maps and is very detailed because of the intent to also use it for a sediment survey.

Because of the man-hours required, the process was both time intensive and expensive. However, mapping for modeling purposes only does not normally have to be that detailed.

### Application of CE-QUAL-W2

The model is designed to be applied to a wide range of water bodies. It is best suited for relatively long and narrow reservoirs that display water quality gradients in both the longitudinal and vertical directions. Each reservoir, though, is unique and exhibits its own particular hydrodynamic characteristics. It is imperative to study the water quality data and to determine what's going on from a limnological standpoint before applying CE-QUAL-W2.

Proficiency at calibration of the model for a given reservoir is gained primarily through experience. Initial calibrations, involving basic parameters such as dissolved oxygen and temperature, are somewhat mechanical. Subsequent calibrations pertaining to biological functions and nutrient dynamics are more complicated and are often more of a developed art than a science. Because of the interrelationships of various constituents, calibration runs eventually reach a point of diminishing returns.

### Additional Problems in Working with Model

It was initially planned to make "mock" calibration runs using previous years' data from both a wet year and a dry year. This would provide experience seeing how the model reacts under variable conditions. This opportunity was lost because of falling behind schedule for various reasons—field sampling, attendance at meetings, delayed laboratory results, etc.

Revisions were made to CE-QUAL-W2 and the user's manual during the course of the Caesar Creek study. The user's manual was changed and updated twice. The surface water reaeration formula was reworked by Tom Cole of WES, as was the pH-alkalinity-$CO_2$ interaction. Both of these modifications were undertaken to facilitate application of the model to Caesar Creek Lake.

## Benefits of Model Application

A number of informational benefits accrued from the development of the model for this reservoir. One was the demonstration of the presence of a metalimnetic minimum in the lake. It was also discovered that basic constituents such as dissolved oxygen and temperature can be calibrated with a high degree of accuracy. We obtained insight into the complex biological and chemical interactions at work in an aquatic ecosystem. We learned that phosphorus is a limiting nutrient for algal growth and development. Also, collection of sufficient inflow nutrient data is imperative to the continued use of the model. CE-QUAL-W2 is a powerful tool for evaluating current and future water quality conditions as affected by changes in nutrient input, particularly phosphorus.

## Lessons Learned

### Dedicated Computer

Modeling requires a computer with sufficient speed and memory designated solely for model work and nothing else. The minimum configuration is an 80386/80486 PC with a math coprocessor. A minimum of four megabytes of memory is necessary.

A hard disk with 10 to 15 Mb of available space is also needed. For an 80386 PC or greater operating under DOS, the user must have a 32 bit FORTRAN compiler with a DOS extender. If using Unix or OS/2, the user must have a FORTRAN compiler compatible with his operating system.

### Dedicated People

Modeling with CE-QUAL-W2 is an ongoing and time-consuming process. It must maintain a priority status in order to meet scheduled

deadlines. Members of the modeling team must be flexible in working modeling responsibilities into their schedule of activities when necessary. The modeling effort for Caesar Creek Lake was most productive when all members of the team were present and working together to make calibration runs and solve problems.

### Laboratory Results

Prior to beginning the study, specify to the testing laboratory the detection limits needed for reportable data. Make sure they are compatible with the laboratory procedures being utilized. Also, make sure the laboratory can provide satisfactory turnaround time on water samples submitted. This will help expedite set-up and calibration of the model and reduce unnecessary delays.

### Computer Resource Person

It is extremely helpful to have a person on the modeling team who is knowledgeable of computers and FORTRAN programming. In lieu of this, you should have someone readily accessible, either in person or by phone, to answer questions when needed.

### Model Itself

Be sure sufficient time and funds are allotted at start-up for the development of the bathymetry. When making calibration runs with the model, be sure to identify each run and keep track of changes in a logbook. This will help avoid confusion and prevent repetition of the same changes. Finally, when plotting and viewing, make sure the graphing software can display the results in the desired format.

The importance of sampling of inflow waters needs to be emphasized over that of lake samples. Inflow data drive the model, while lake samples are used to compare observed versus simulated constituent values for model calibration. The more inflow data available, the easier is model calibration and use. Inclusion of the effect of storm events on inflow water quality is also recommended. Storm-induced variations in inflowing materials, especially nutrients and sediment, are useful in evaluating best means of land-use practices.

## Recommendations

Continued use of CE-QUAL-W2 is strongly recommended as an important part of the Corps' water quality and environmental studies. Improved strategies for maintaining water quality in Caesar Creek Lake are possible with CE-QUAL-W2 because the model has the capability to integrate all the different factors involved. Experience gained in applying the model to Caesar Creek Lake will be beneficial during application to the Corps' other projects. CE-QUAL-W2 should be utilized as the primary tool for all actions and decisions that may affect the future water quality of the reservoir.

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# Metropolitan Nashville Regional Environmental Engineering Study

*by*
*Tim Higgs*[1]

## Introduction

The Nashville District recently completed a reconnaissance level planning study of environmental problems in the Metropolitan Nashville area. The District was to "conduct a regional environmental engineering study to identify and quantify point and nonpoint sources of pollution and associated sources that contribute to pollution problems." The study area was defined as the watersheds of three large Corps lakes in the Nashville area: Old Hickory, Cheatham, and J. Percy Priest lakes. Primary purposes of the study were to define the nature and extent of environmental problems in the lakes and watersheds and identify at least one viable measure to improve each problem. This paper presents a summary of some problems evaluated during the study.

## Description of the Cumberland River Basin

The study area consisted of the watersheds of three of the nine large Corps water resource projects in the Cumberland River basin of Tennessee and Kentucky. These nine projects comprise a system of reservoirs that produce both regional benefits such as navigation, flood control, and hydropower and regional and local environmental effects because of alterations of the natural flow regime and water quality.

Water resource projects in the Cumberland River basin can be broken into two general classes: main stem reservoirs operated primarily for navigation and hydropower and tributary storage projects operated primarily for flood control and hydropower. Each class of reservoirs has a different set of environmental problems and opportunities. Old Hickory and Cheatham lakes are main stem projects at Cumberland River miles 216.2 and 148.7, upstream and downstream of Nashville. J. Percy Priest Lake is a tributary storage project on the Stones River, a tributary of Cheatham Lake just east of Nashville. The watersheds of these projects were interpreted to include all stream reaches to the next upstream Corps project(s). For example, the Old Hickory watershed included the tailwaters of Cordell Hull and Center Hill dams.

## Regional Land-Use Patterns

Land uses within the study area have changed significantly since the first Corps dam was constructed in 1943. As the population of Metropolitan Nashville increased, many areas have been converted from agricultural to urban/suburban land uses. In general, agriculture has declined across the region. As part of this study, 1985 LANDSAT images were classified by a local university to aid in the evaluation of potential impacts from nonpoint source pollution. The watershed of each lake was subdivided so that a ranking of potential impacts could be made. This evaluation is expected to be repeated periodically to look at trends.

In general, land uses change from urban to rural as you move away from the Nashville area. For each lake, significant areas of the watershed have exhibited a higher rate of urban development. For example, the population of Rutherford County, which is part of the J. Percy Priest watershed, increased by 38 percent during the 1980s. The downstream portions

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[1] U.S. Army Engineer District, Nashville; Nashville, TN.

of the Old Hickory and J. Percy Priest watersheds and the upstream portion of the Cheatham Lake watershed contain more urban development. The outlying areas are a mix of forested and agricultural areas.

One problem with the land-use classification scheme used in this study was that many areas of less dense residential development were classified as open-mixed land use because of the resolution of the data. It was felt that this underestimated the actual area impacted by suburban/urban land usage.

## Nonpoint Sources of Pollution

Several factors make it difficult to quantify impacts from nonpoint sources. Many impacts, such as bank erosion or stress on aquatic life, are gradual and subtle. Water quality varies dramatically during storm events. Sources such as construction sites are temporary in nature. Under base-flow conditions, a stream may appear to be of high quality; therefore, habitat-biological surveys are often the best monitoring method. Reservoir models may be needed to consider impacts of nutrients and sediment on downstream water bodies.

Because of these difficulties, nonpoint source control efforts are not a high priority for State and local regulatory agencies. In Tennessee, enforcement mechanisms are set up for dramatic impacts, such as fish kills or long-term discharge permit violations, where damage documentation can be built over time. For nonpoint source construction problems, a "ticket-writing" approach is needed to help ensure that best management practices (BMPs) are utilized to minimize impacts from development since it is often difficult to show impacts from an individual site.

Many stream and lake reaches in the study area have been degraded from unstable storm water conveyance systems, removal of riparian vegetation, and increased runoff rates. Most rural counties have little in the way of design standards for subdivisions. Some local governments have building codes that address these problems on paper; but in reality, no oversight is provided to ensure that standards are followed. In addition, the recent storm water permit requirements for construction sites greater than 5 acres have provided little control to date since this program is largely voluntary on the developers part with little oversight by the State regulatory agency. The result is widespread areas with eroding drainageways, streams with severe bank erosion, and embayment areas choked with sediment from watershed sources. Even with the haphazard controls, most of the regions streams are of relatively good quality, but many could be of better quality.

Impacts from urban nonpoint sources are a common problem across the Nashville area since there exists little or no control on urban development. An "ideal" nonpoint source control program was outlined in the study report based on review of similar programs from other urban areas such as Washington, DC. A successful program requires a coordinated local, State, and Federal effort with local agencies driving the program. The approach recommended in this report is to utilize a "watershed management program" that identifies and protects significant resources in a watershed, provides comprehensive cost-effective restoration of past man-induced impacts, and minimizes future impacts by effectively enforcing existing building codes and storm water permit rules. Several key watersheds in the region were identified as in need of detailed evaluation and restoration efforts.

## J. Percy Priest Lake and Watershed

J. Percy Priest Lake is located just east of Nashville on a Cumberland River tributary, the Stones River. The drainage area of the lake is 892 square miles. The project is operated to maintain a relatively constant summer recreation pool level. Hydropower generation may be curtailed for long periods of times (months) because of low inflows during dryer months. This is necessary if summer pool elevations are to be maintained. The lake is considered eutrophic, partly because of high

background phosphorus levels from geologic conditions in the Stones River basin. Strong thermal stratification develops in the lake, with dissolved oxygen (DO) usually absent below a depth of 15 to 20 ft.

## J. Percy Priest Tailwater Restoration

The 7-mile tailwater of J. Percy Priest is highly impacted by the operation of the dam. The lower 4 miles is backwater from the Cumberland River (Cheatham Lake). The lack of a minimum flow release from the project impacts aquatic habitat, and poor quality of hydropower releases violates water quality criteria on a seasonal basis.

Alternatives for providing a continuous minimum flow release from the project were evaluated. The recommended alternative was to provide a continuous flow from the project by a floating syphon system that would release higher quality surface water from the lake under summer pool levels. The initial goal is to release 10 to 15 cfs, which also matches the preproject historical low flow (3Q20). During winter months, this release would be provided by slightly cracking a spillway gate since the syphon system would not work under winter pool levels because of the lift required.

To address hydropower releases, a system of six localized mixing devices (LMDs) were installed in 1988. The LMDs work by pushing high-quality surface water down into the withdrawal zone of the hydropower units. To date, this system has not been operational because of structural design problems. Currently, an architect/engineer (A/E) contractor is redesigning the structural mechanism that holds the LMDs in place. Coupled with the continuous flow syphon discussed in the previous paragraph, the Stones River downstream of the dam should be vastly improved for both habitat and water quality.

## Old Hickory Lake and Watershed

Old Hickory Lake is a main stem reservoir that develops thermal stratification in its lower half. The degree of stratification is primarily controlled by releases from upstream projects during summer months. Average annual detention time of the project is about 11 days, but can increase to 30 days during the summer months. Hypolimnetic DO levels have been as low as 2 mg/L during periods when detention times increase above 20 days. As a result, DO levels of hydropower releases can be as low as 4 mg/L. Old Hickory Dam is considered the control point for DO levels on the main stem Cumberland River.

A secondary influence on DO levels in the lake is nutrient loadings from the local watershed. Much of the lower local watershed has experienced rapid urban development, with several tributaries listed by the State as threatened because of urban nonpoint impacts. Eutrophic conditions develop in the lake, and algae-related taste and odor problems periodically occur in water systems using the Cumberland River in and downstream of Old Hickory Lake.

## Old Hickory Dam Water Quality (DO Levels)

Probably the most significant regional water quality problem that can be controlled by the Corps' operation is the quality of releases from Old Hickory Dam. Low DO levels from the project increase wastewater treatment requirements on dischargers to the Cheatham Lake pool, including Nashville. Both structural and operational methods to improve DO levels were evaluated as part of this study. The U.S. Army Engineer Waterways Experiment Station assisted in the review of structural methods. Two objectives examined were meeting DO criteria (5.0 mg/L) from the project and supplementing release DO levels

above the criteria (to 6.0 mg/L) to benefit waste assimilation for downstream dischargers.

The recommended structural method for both objectives was a pulsed hypolimnetic oxygenation system because of the advective nature of Old Hickory Lake. This method was compared with the operational method described in the following paragraph to determine the best alternative for meeting DO standards from the project.

The District has developed a Cumberland River system model for temperature and DO. The dissolved oxygen routing model (DORMII) simulates the basin by routing releases from three upstream storage projects through the four main stem projects. By using the DORMII model, minimum flow criteria have been developed to keep detention time through Old Hickory Lake low enough to prevent violations of DO criteria from the project. A set of bi-weekly flow criteria was developed and has been adopted into the operation of the reservoir system. Conditions are monitored through critical periods to adjust main stem flow requirements based on current meteorological conditions. It should be noted that if watershed nutrient loadings increase, this flow criteria may not be adequate. The average annual cost of implementing this criteria was estimated to be $8,800.

## Fisheries Impacts in the Upper Old Hickory Lake Pool

At the request of the Tennessee Wildlife Resource Agency (TWRA), the District evaluated methods for improving conditions for sauger and paddlefish spawning in the upper reaches of Old Hickory Lake. The river reach impacted consists of the upper 15 miles of the lake below Cordell Hull Dam. The TWRA provided initial continuous flow recommendations intended to maintain adequate velocities to reduce sediment accumulation in spawning beds during the spawning period (April). The District evaluated the recommendations and performed operational tests to determine if the hydropower units could be operated in the flow range needed. After this review, a continuous flow of 4,000 cfs (one generator at 50-percent capacity) could be provided without mechanical problems. The District is currently in the second of a three-trial period for this operation. The success of the operation will be monitored by TWRA by measuring the amount of young fish impinged at the intake screens of a downstream power plant.

## Center Hill Dam Tailwater

The second largest inflow to Old Hickory Lake is the Caney Fork River. Releases from Center Hill Dam at mile 26.6 produce a coldwater put-and-take trout fishery. Alternatives for improving water quality conditions in the lower Caney Fork River were examined during this study. Actions are needed to address both quality (DO and temperature) and aquatic habitat (minimum flow and substrate). The existing minimum generation criteria of one hydropower unit for 1 hr every 48 hr are inadequate to maintain coldwater temperature criteria during weekends. Hydropower releases during late summer and early fall can be extremely low in DO (to 2.0 mg/L).

The recommended alternatives attempted to address both quality and habitat considerations. To provide a continuous flow of 200 cfs from the dam, a reregulation weir was recommended. The 200-cfs flow rate was previously determined as optimizing the available aquatic habitat (wetted area) in the downstream channel. Additional seasonal hydropower pulsing (up to 500 day-second-feet) would be needed in order to maintain temperature criteria in the downstream channel. To improve hydropower DO levels, turbine venting was recommended as an initial step, although it alone will not meet DO criteria under all conditions. Hypolimnetic aeration would be necessary if coldwater temperature conditions are to be maintained at all times. The significance of low DO levels has not been considered a critical issue in the past because of reaeration in the downstream channel.

An 1135 project was also proposed for the Caney Fork River to improve aquatic habitat by placing boulders in critical areas downstream of the reregulation pool. The bottom substrate is scoured in the first few miles because of hydropower generation. This project was supported by the TWRA.

## Aquatic Habitat of Embayments of Old Hickory Lake

Methods to improve aquatic habitat within several embayments of Old Hickory Lake were evaluated. Many headwater areas contain wide, shallow mudflats and degraded water quality. Because of relatively constant pool levels, emergent wetland vegetation is developing over time. A proposal was made to speed the development of wetland vegetation in these headwater areas. Breakwater structures (wing dikes) were proposed to improve bottom substrate stability. Selected plantings of wetland vegetation were also proposed to supplement current vegetation. This alternative is intended to provide both water quality, aquatic habitat, and recreational benefits. In theory, each embayment should have some cumulative effect on overall lake water quality. Watershed sources of sediment must also be controlled.

## Cheatham Lake and Watershed

Cheatham Lake is a narrow riverine-type lake with detention times usually in the 2- to 7-day range. Because of the narrow morphometry and relatively high flow rate, thermal stratification is weak or absent. The lake does develop DO stratification and exhibits a high degree of algal activity, which is related to the high nutrient levels in the lake. Nutrient sources are point sources, combined sewer overflows, and urban nonpoint sources. Low DO levels are inherited from releases of Old Hickory Dam. Because reaeration is low, the initial inflow DO levels dominate conditions throughout the lake. Because of algal oxygen production and the lack of thermal stratification, release DO levels from Cheatham Dam are not a problem.

The most critical issue within the Cheatham Lake pool was initial low DO levels and impacts on downstream dischargers. Nashville is currently planning and designing controls for a 9,000-acre area of combined sewers and is expanding its wastewater treatment plants. A local A/E firm for Nashville has applied the CE-QUAL-W2 model to Cheatham Lake to aid in evaluations of various treatment scenarios and effects of background water quality conditions.

At the request of the Corps, the A/E firm performed model runs using the biweekly flow criteria determined for maintaining a DO of 5 mg/L in releases from Old Hickory Dam. The intent of these runs was to see if additional flow or improved DO levels were needed. The modeling determined that with the maintenance of 5.0 mg/L from Old Hickory Dam, assimilation of wastewater discharges from Nashville would be acceptable based on expanded design loadings from point sources and combined sewer overflows. This combined modeling effort illustrates the importance of integrated water management by local, State, and Federal agencies.

## Conclusion

The Metropolitan Nashville Regional Environmental Engineering Study looked at a variety of issues addressing regional water quality issues. Some alternatives addressed items under direct control of the Corps' operation, for example minimum flow from dams. Other problems are the result of a wide variety of land-use activities, and solutions would require actions by a variety of local, State, and Federal agencies. If the quality of the region's streams and lakes are to be maintained, better control of urban development is needed. Several key watersheds were identified for detailed studies to address nonpoint source problems. Consistent controls on development are needed across the region. Because of the wide variety of water users, water resource management is much more complex today; managers must consider interrelated impacts on all uses.

# Variables Influencing the Productivity and Diversity of Reservoir Tailwater Fisheries in the Upper Ohio River Drainage Basin

*by*
*Michael Koryak* [1] *and Robert Hoskin*[1]

## Introduction

Reservoir tailwaters are generally very attractive to both fish and fishermen. For example, as has been demonstrated at two Corps of Engineers projects in the upper Ohio River drainage where creel surveys have been conducted, Kinzua and Tygart dams, fishermen utilization of these relatively small tailwater areas might approach or even sometimes exceed utilization of the comparatively much larger upstream reservoirs. At Kinzua Dam, for instance, Griffiths (1985) found that there were about 20,000 angler trips to the 5,000-ha lake and 12,000 angler trips (38,024 hr) to the very much smaller tailwater area annually. Jernejcic (1982b) documented similar results at Tygart where the annual fishing pressure amounted to 49 hr per hectare in the reservoir and 1,196 hr per hectare in the tailrace. Anglers also tended to be much more successful in the tailwaters. During 1981-82, for example, in spite of intense tailwater fishing pressure, the angler catch per unit effort for walleye at Tygart was 0.56 in the tailwaters compared with 0.32 in the reservoir.

The tailwaters of Corps of Engineers reservoir projects are then or have the potential to be extraordinarily important recreational resources. This study is a summary of spring and autumn electrofishing surveys of the tailwaters of 16 Corps of Engineers impoundments in the upper Ohio River drainage basin. The study area and project locations are shown on Figure 1. The basin includes 40,000 km$^2$ of western Pennsylvania, northern West Virginia, northeastern Ohio, and small portions of western New York and Maryland. This basin includes both glaciated and unglaciated portions of the Appalachian Plateaus physiographic province, as well as the Allegheny Mountains.

The glaciated region, which is located northeast of the limit of glaciation shown on Figure 1, could be characterized as typically of low relief with a high percentage of land use devoted to agricultural activities. Reservoirs in this region tend to be summer warm, shallow, and fertile.

The above reference to the fertility of the water of this physiographic region is highly pertinent. As discussed by Lee and Jones (1991), the trophic state of water has long been recognized as a primary variable influencing fishery resources. The greater the amount of nutrients and planktonic algae available, typically the higher the fish yield. There is, however, a negative side to this relationship, and advanced eutrophication can lead to degradation in the quality of fisheries. For instance, fisheries of highly eutrophic waters generally tend to be dominated by carp and other rough fishes that are considered by most North Americans to be undesirable. Stunted panfish populations are another qualitatively negative impact frequently associated with highly eutrophic waters.

In contrast to the glaciated plateau, the unglaciated plateau located in the southeastern portion of the upper Ohio River drainage basin is mostly a forested, maturely dissected, and high relief peneplain with limited exposed limestone and abundant fossil fuel resources.

[1] U.S. Army Engineer District, Pittsburgh; Pittsburgh, PA.

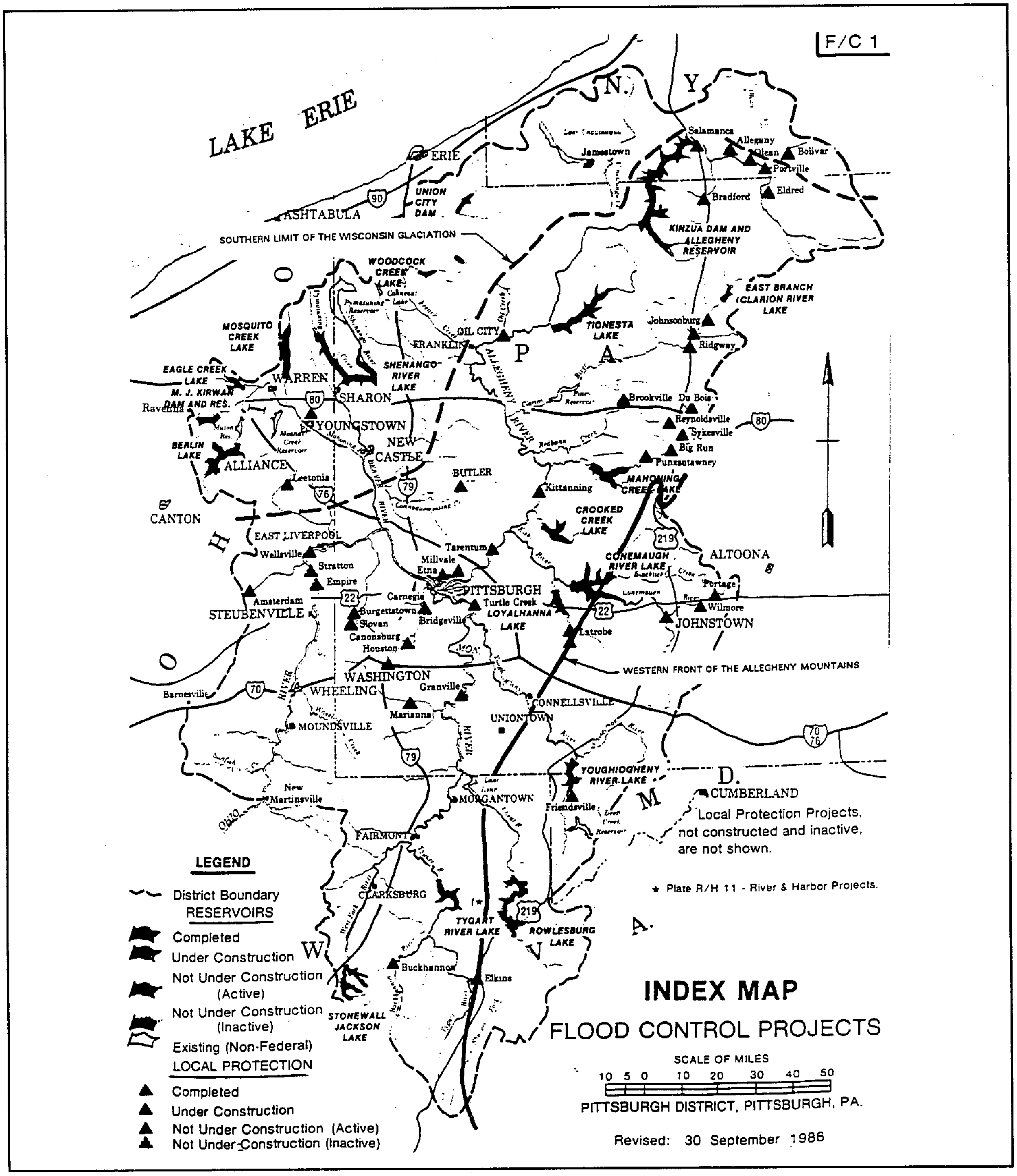


*Figure 1. Index map*

Reservoirs located in the unglaciated plateau and Allegheny Mountains region tend to be deeper and less fertile, often with cool or cold outflow water temperature regimes. In addition, literally thousands of kilometers of streams in this area have been degraded by drainage from bituminous coal mines (Koryak, Shapiro, and Sykora 1972). Pertinent information on the 16 tailwaters sampled during this study is summarized in Table 1.

## Table 1
## Descriptions of Pittsburgh District Reservoirs

| MAJOR DRAINAGE BASIN Project, Three Letter Code, and Location of Tributary Drainage Basin | Impounded Stream | Drainage Area $km^2$ | Reservoir Storage at Summer Pool $m^3 \times 10^3$ | Mean Reservoir Depth at Summer Pool, m | Maximum Reservoir Depth at Summer Pool, m | Trophic State | Hydropower | Discharge Thermal Regime |
|---|---|---|---|---|---|---|---|---|
| BEAVER RIVER DRAINAGE | | | | | | | | |
| Michael J. Kirwan Reservoir MJK, OH, glaciated plateau | West Branch Mahoning River | 208 | 69,911 | 6.5 | 17.7 | mesotrophic | none | warm |
| Berlin Lake BER, OH, glaciated plateau | Mahoning River | 645 | 71,900 | 4.8 | 23.2 | eutrophic | none | warm |
| Mosquito Creek Lake MOS, OH, glaciated plateau | Mosquito Creek | 251 | 99,100 | 3.1 | 13.4 | eutrophic | none | warm |
| Shenango River Lake SHN, PA + OH, glaciated plateau | Shenango River | 1,526 | 36,900 | 2.5 | 9.1 | eutrophic | none | warm |
| ALLEGHENY RIVER DRAINAGE | | | | | | | | |
| Woodcock Creek Lake WCR, PA, glaciated plateau | Woodcock Creek | 118 | 6,100 | 4.5 | 13.4 | eutrophic | none | warm |
| Union City Reservoir FCU, NY + PA, glaciated plateau | French Creek | 575 | 25 | 1.2 | 1.8 | eutrophic | none | cool |
| Allegheny Reservoir/Kinzua Dam KIN, PA + NY, glaciated and unglaciated plateau | Allegheny River | 3,445 | 706,500 | 14.5 | 40.2 | mesotrophic | both pumped storage and run of river | cold |
| Tionesta Lake TIO, PA, unglaciated plateau | Tionesta Creek | 1,238 | 10,100 | 4.6 | 14.0 | mesotrophic | licensed but not constructed | cool |
| East Branch Clarion River Lake EBR, PA, unglaciated plateau | East Branch Clarion River | 189 | 79,300 | 16.9 | 44.8 | oligotrophic | none | cold |
| Mahoning Creek Lake MAH, PA, unglaciated plateau | Mahoning Creek | 881 | 11,700 | 9.7 | 27.4 | oligotrophic | licensed but not constructed | cold |

*(Continued)*

Table 1 (Concluded)

| MAJOR DRAINAGE BASIN Project, Three Letter Code, and Location of Tributary Drainage Basin | Impounded Stream | Drainage Area $km^2$ | Reservoir Storage at Summer Pool $m^3 \times 10^3$ | Mean Reservoir Depth at Summer Pool, m | Maximum Reservoir Depth at Summer Pool, m | Trophic State | Hydropower | Discharge Thermal Regime |
|---|---|---|---|---|---|---|---|---|
| ALLEGHENY RIVER DRAINAGE (Continued) | | | | | | | | |
| Crooked Creek Lake CRC, PA, unglaciated plateau | Crooked Creek | 717 | 8,500 | 4.5 | 13.1 | mesotrophic | none | warm |
| Conemaugh River Lake CON, PA, Allegheny Mountains and unglaciated plateau | Conemaugh River | 3,499 | 6,800 | 2.1 | 6.1 | oligotrophic | run of river | warm |
| Loyalhanna River Lake LOY, PA, Allegheny Mountains and unglaciated plateau | Loyalhanna Creek | 751 | 4,300 | 3.0 | 14.9 | mesotrophic | none | warm |
| MONONGAHELA RIVER DRAINAGE | | | | | | | | |
| Youghiogheny River Lake YOU, PA, and MD, Allegheny Mountains | Youghiogheny River | 1,124 | 190,500 | 16.6 | 36.9 | mesotrophic | run of river | cold |
| Tygart River Lake TYG, WV, Allegheny Mountains and unglaciated plateau | Tygart River | 3,067 | 135,100 | 19.2 | 40.8 | mesotrophic | licensed but not constructed | cool |
| Stonewall Jackson Lake WFS, WV, unglaciated plateau | West Fork River | 264 | 59,200 | 5.8 | 22.5 | eutrophic | station only | cool |

## Methods

The primary implement for fish collection during the investigation was a 4.9-m electrofishing boat. A 5,000-W generator supplied the alternating current (AC), and a variable voltage pulsator (Coffelt, VVP-15) controlled output. Three electrodes, each 1.2 m long, hanging off a 3-m-wide bow boom, transferred the electricity to the water. As the fish were shocked, dip nets were used to collect them. The desired collection technique was to have two people on the bow platform and two other people in the boat (including the operator) to pick up the fish missed by the bow platform crew. Shallow-water habitats were backpack electrofished.

Except for a few reference specimens that were preserved in formalin, the fish collected were kept alive and released after processing. All the fish were measured to the nearest millimeter and subsamples were weighed to the nearest gram.

For the purpose of this study, reservoir tailwaters were rather narrowly defined to be stream segments extending from the toes of the dams downstream to and including the first downstream riffles. Any oxbows, embayments, accessible tunnels, or other contiguous aquatic habitats between the dams and these riffles were also considered to be part of the project tailwaters. Where stilling weirs were part of the design of the dams, tailwaters were considered to extend downstream to and include the first riffles downstream of stilling weirs. An exception to this definition was applied at Conemaugh Dam, where the pool below a hydropower plant located 500 m downstream of the dam and below a riffle was also considered to be an integral component of the project tailwaters. Except for Conemaugh Dam, none of the tailwaters sampled during this investigation exceeded a length of 350 m. Circumstances mandated that the definition also be somewhat compromised at three other projects. Since the first riffle downstream of the stilling basin of Tygart Dam is more than 6 km downstream, at this project the investigators just sampled the first 350-m reach of this very long pool. Conversely, since the first riffles downstream of both Loyalhanna and Mahoning Creek Dams begin less than 20 m downstream of the toe of their stilling weirs, it was necessary to extend the length of the stream segments electrofished at these two projects to obtain an area of sufficient dimensions for reasonable and representative samples.

## Results

A total of 7,469 fish of 70 species from 15 families plus several hybrids, with a combined weight of 1,200 kg, were collected during this investigation. The number of fish species collected, electrofishing effort and catch per unit effort (CPUE as fish/hr), total weight and number of fishes collected, the percentages of samples that were gamefish and panfish, the percentage weight of the sample that was gamefish, and the biomass collected per unit effort (kilograms/hour) from each of the 16 reservoir tailwaters sampled is summarized in Table 2.

Major variables that might influence the diversity and productivity of the different tailwater fisheries are examined in Table 3. As can be noted in Table 3, tailwaters with warmwater and coolwater discharge temperature regimes tended to be somewhat more diverse and about 300 percent more productive than coldwater discharge regime tailwaters. Nonetheless, since the coldwater temperature regime tailwaters support year-round trout fishing, they are generally perceived by the local public and resource agencies to be high quality fisheries. In fact, a previous resource agency proposal to increase the productivity of one project, Allegheny Reservoir/Kinzua Dam, by operating to warm its discharge met with fierce public resistance.

Since low-elevation withdrawal outlet works withdraw cooler waters during the water temperature limiting period of summer stratification than near-surface and mid-level withdrawal outlets, it may seem surprising

**Table 2**
**Summary of Results of Tailwater Electrofishing Surveys of Pittsburgh District Reservoirs, 1986 - 1990**

| Project Tailwater | Number of Species | Effort, hr | Catch per Unit Effort fish/hr | Total Weight of Fish, g | Total Number of Fish | % Gamefish | % Panfish | % of Weight Gamefish | Biomass per Unit Effort kg/hr |
|---|---|---|---|---|---|---|---|---|---|
| M.J. Kirwan | 24 | 2.17 | 170 | 119,021 | 368 | 83.4 | 69.8 | 73.9 | 54.8 |
| Berlin | 18 | 0.50 | 1,366 | 131,222 | 683 | 47.9 | 15.7 | 65.7 | 262.4 |
| Mosquito Creek | 26 | 1.00 | 833 | 36,967 | 833 | 76.5 | 70.1 | 88.5 | 37.0 |
| Shenango River[1] | 30 | 1.00 | 719 | 139,389 | 719 | 54.9 | 41.3 | 33.9 | 139.4 |
| Woodcock Creek | 30 | 1.50 | 280 | 56,400 | 420 | 52.6 | 38.0 | 38.2 | 37.6 |
| Union City | 37 | 1.37 | 734 | 257,334 | 1,005 | 30.7 | 20.4 | 16.2 | 187.8 |
| Kinzua[2] | 27 | 2.00 | 115 | 106,725 | 230 | 19.1 | 3.0 | 15.8 | 53.4 |
| Tionesta | 36 | 4.33 | 250 | 111,867 | 1,081 | 69.6 | 58.1 | 81.0 | 25.8 |
| East Branch Clarion River | 10 | 1.75 | 169 | 13,350 | 296 | 55.1 | 48.3 | 50.3 | 7.6 |
| Mahoning Creek | 32 | 4.75 | 79 | 41,068 | 375 | 23.2 | 15.7 | 25.0 | 8.6 |
| Crooked Creek | 32 | 2.50 | 294 | 123,861 | 736 | 48.0 | 37.5 | 22.6 | 49.5 |
| Conemaugh River (1986) | 3 | 2.42 | 4 | 347 | 9 | 88.9 | 88.9 | 95.7 | 0.1 |
| Conemaugh River (1988-89) | 11 | 2.75 | 69 | 17,621 | 190 | 93.7 | 93.2 | 50.2 | 6.4 |
| Loyalhanna | 18 | 2.92 | 109 | 33,400 | 318 | 73.3 | 65.4 | 43.3 | 11.4 |
| Youghiogheny River[2] | 19 | 1.67 | 41 | 6,842 | 69 | 79.7 | 59.4 | 82.1 | 4.1 |
| Tygart[2] | 13 | 1.50 | 31 | 5,420 | 47 | 74.5 | 38.3 | 91.8 | 3.6 |
| Stonewall Jackson[2] | 16 | 0.83 | 108 | 5,836 | 90 | 91.1 | 52.2 | 72.7 | 7.0 |
| Total | | 34.96 | | 1,206,670 | 7,469 | | | | |

1 There was a sampling procedure bias in the spring 1988 survey of the Shenango River Dam tailwaters that makes quantification of this data inappropriate. Therefore, both spring and fall data were used only in the listing of the number of species present. All other information on the Shenango River Dam tailwater is based only on the fall 1988 survey data.
2 Data based on one survey conducted during the spring season. All other projects surveyed twice, once in the spring and once in the fall.

**Table 3**
**Comparisons of Fishery Diversity and Productivity at Reservoir Tailwaters in the Upper Ohio River Drainage Basin Grouped by Discharge Water Temperature Regimes, Water Quality, Withdrawal Design and Operational Characteristics, and Regional Geology, 1986-1990**

| | Number of Species Collected | Catch per Unit of Effort fish/hr | Biomass per Unit of Effort kg/hr |
|---|---|---|---|
| All Reservoir Tailwaters (17 projects)[1] | | | |
| Maximum | 37.0 | 1,366 | 262.4 |
| Minimum | 3.0 | 4 | 0.1 |
| Mean | 22.6 | 316 | 52.7 |
| Comparisons for Different Water Temperature Regimes | | | |
| Mean for coldwater regimes (3 projects) | 19.0 | 108 | 21.7 |
| Mean for warmwater and coolwater regimes (14 projects) | 23.4 | 360 | 62.4 |
| Comparisons for Varying Degrees of Acid Mine Drainage (AMD) Degradation | | | |
| Mean for tailwaters with severe AMD (1 project) | 3.0 | 4 | 0.1 |
| Mean for tailwaters with moderate AMD (3 projects) | 13.0 | 116 | 8.5 |
| Mean for tailwaters with negligible AMD (13 projects) | 26.4 | 386 | 66.9 |
| Comparisons for Various Withdrawal Elevations | | | |
| Mean for surface and mid-level withdrawal (5 projects) | 21.6 | 168 | 32.1 |
| Mean for bottom withdrawal (12 projects) | 23.1 | 377 | 61.3 |
| Comparisons for Different Geologic Regions | | | |
| Mean for Glaciated Appalachian Plateau (6 projects) | 27.7 | 684 | 119.8 |
| Mean for Unglaciated Appalachian Plateau and Allegheny Mountains(10 projects) | 19.2 | 127 | 12.4 |
| Mean for Glacial Boundary (1 project) | 27.0 | 115 | 53.4 |
| Mean for Unglaciated Plateau and Allegheny Mountains without AMD pollution (6 projects) | 25.0 | 153 | 16.4 |

[1] Because of the extreme changes in the water quality and fishery of the Conemaugh River Dam tailwater that occurred between 1986 and 1988, pre- and post-1987 Conemaugh Dam data are listed and examined separately, as if it were two different projects.

that of the reservoir projects compared in Table 3, the tailwater fisheries below dams with bottom withdrawal tended to be more diverse and about twice as productive as those with higher elevation withdrawal. This apparent contradiction of the previous conclusions about tailwater thermal regimes, however, is largely a consequence of the fact that in the upper Ohio River drainage, bottom withdrawal is more typically associated with the summer warm, shallow, and eutrophic impoundments of the glaciated Appalachian Plateau region than of the deeper, cooler, and less fertile reservoirs in the unglaciated plateau and Allegheny Mountain regions. Therefore, regional geologic and water quality variations seem to be obscuring the influence of withdrawal elevation on the characteristics of these tailwater fisheries.

The potential for this regional physiographic difference to overwhelm the effects of other variables is readily apparent in the Table 3 comparison of mean numbers of fish species collected and CPUE values for the six tailwaters in the glaciated Appalachian Plateau with the 10 projects in the unglaciated plateau and Allegheny Mountain region. This comparison demonstrates that the tailwater fisheries in the glaciated region were about 150 percent more diverse and produced about 540 percent more fish per hour of sample effort and about 1,000 percent more fish biomass per hour of sampling effort than the tailwater fisheries of the unglaciated plateau. Even correcting for the devastating impacts of acid mine drainage pollution in the unglaciated plateau and Allegheny Mountain region, the tailwater fisheries in glaciated regions were still

overwhelmingly more productive (450 percent numerically and 730 percent biomass) than the tailwater fisheries of the unglaciated regions. As the Table 3 comparison shows, these regional variations in water quality, geology, and reservoir morphology can impose intrinsic limitations on the potential of a tailwater fishery.

There are a number of tailwater design alternatives available that can improve the recreational fishing potential of a tailwater. Two important such options that became apparent during this study were the design of stilling weirs, especially in respect to locating public access facilities, and the creation of physical structures such as tailwater embayments.

What is known as the Crooked Creek Dam Outflow Handicapped Access Fishing Embayment serves as an excellent example of a structural modification that can greatly enhance a tailwater fishery. The Pittsburgh District Corps of Engineers and local volunteers excavated this shallow 0.20-ha embayment a short distance downstream of Crooked Creek Dam in 1985 for the primary purpose of providing wheelchair-fishing access to its tailwaters. Table 4 compares the fishery of the cooler flowing waters of the Crooked Creek tailwaters with the warmer still waters of the embayment. CPUE was higher in the embayment than in the stream segment of the tailwaters, and the percentages of the sample that were game and panfish were much higher in the embayment. Species with preferences for cooler flowing waters such as smallmouth bass, walleye, and sauger were clearly segregated in the stream area, while more typical lentic water species such as largemouth bass and white crappie piled up in the embayment. We suspect that the embayment acts as a holding area for entrained lake fishes blown out through Crooked Creek Dam.

The likelihood that Crooked Creek Lake is an important source of the fish holding in the Crooked Creek tailwater embayment is supported by numerous examples in the literature of downstream movements through dams.

**Table 4**
**A Comparison of Fishery Data from the Crooked Creek Dam Tailwater and from Adjacent Outflow Embayment**

| | Crooked Creek Dam Tailwater | |
|---|---|---|
| | Proper to First Downstream Riffle | Handicapped Access—Fishing Embayment |
| Area electrofished, ha | 0.24 | 0.20 |
| Electrofishing effort, hr | 1.58 | 0.92 |
| Number of species captured | 29 | 17 |
| Total number of fish | 444 | 292 |
| Catch per effort, fish/hr | 282.30 | 317.40 |
| % gamefish | 27.00 | 79.80 |
| % panfish | 17.30 | 68.20 |
| % of gamefish desirable size | 16.70 | 9.00 |

Some examples include the many reported in a literature review of tagging and radiotelemetry studies of fish movements through dams on the upper Mississippi prepared by Holland et al. (1984). It is interesting to note in this review that the Wisconsin Department of Natural Resources reported following one particularly hyperactive walleye as it moved upstream and downstream through Mississippi River Navigation Lock and Dam 4 five different times within one 24-hr period. Jernejcic (1982a) also clearly demonstrated that the excellent walleye fishery of the lower Tygart River was entirely dependent upon entrained fish from Tygart Lake being blown through Tygart Dam during mostly late winter high-discharge events. Similarly, we found species abundant in Crooked Creek Lake packed into its tailwater embayment after high-discharge events at Crooked Creek Dam.

Smallmouth bass, walleye, and trophy fishermen in general still tend to work the stream segment of the Crooked Creek tailwaters. However, there is now also an alternative panfishery in the embayment portion of the tailwaters which, in spite of its very small size, is an outstanding and very popular recreation resource. A handicapped access fishing pier has been constructed in the embayment that is heavily utilized by anglers including handicapped and older and younger fishermen, who would

have difficulties in both accessing and fishing in the more difficult terrain of the stream segment of the tailwaters.

Having noted the manner in which the Crooked Creek Dam outflow embayment improved the diversity and productivity of its tailwater fishery, we examined a similar small, shallow, and weedy tailwater embayment located at the toe of the dry pool Union City Dam project. Table 5 is a comparison of the fisheries of the 0.40-ha stream and the 0.24-ha embayment portions of the Union City Dam tailwaters. The CPUE in the embayment was almost double that of the stream segment, as were the percentages of both gamefish and panfish. Again, smallmouth bass, walleye, and narrow-bodied suckers were concentrated in the stream segment. The sample from the embayment portion of the Union City Dam tailwaters was numerically dominated by bluegill and other small panfish, but also had unusually dense populations of largemouth bass and northern pike.

**Table 5**
**A Comparison of Fishery Data from the Union City Dam Tailwater and from Its Adjacent Outflow Embayment**

| | Union City Dam Tailwater | |
|---|---|---|
| | Proper to First Downstream Riffle | Outflow Embayment |
| Area electrofished, ha | 0.40 | 0.24 |
| Electrofishing effort, hr | 1.03 | 0.35 |
| Number of species captured | 34 | 20 |
| Total number of fish | 639 | 366 |
| Catch per effort, fish/hr | 620.40 | 1,045.70 |
| % gamefish | 23.00 | 44.30 |
| % panfish | 15.00 | 29.80 |
| % of gamefish desirable size | 42.90 | 34.60 |

These data and observations strongly suggest that the construction of embayments in the tailwaters of other dams could substantially enhance not only the quality of their fisheries but also in many cases their accessibility and fishability for expanded categories of anglers.

The design of stilling weirs was another variable observed to very significantly influence the local distribution and abundance of fish in reservoir tailwaters. For example, as shown in Table 6, there is a profound difference in the quality and quantity of fish present in reaches upstream and downstream of the Mahoning Dam stilling weir. This weir is 5.3 m high and impounds a 1.7-ha stilling pool. The fish biomass CPUE was 1,900 percent higher in the pool downstream of this weir than in the stilling pool, and this data were collected during the spring when we were probably blowing out walleye through the dam directly into the stilling pool. However, as previously discussed, walleye are very mobile fish. They apparently don't hold there for long, and once over this high weir, they can't reenter the stilling pool.

**Table 6**
**A Comparison of 1986 Fishery Data Collected Upstream and Downstream of the 17.5-ft-High Mahoning Creek Dam Stilling Basin**

| | Upstream of Weir | Downstream of Weir |
|---|---|---|
| Area electrofished, ha | 1.70 | 1.01 |
| Electrofishing effort, hr[1] | 1.58 | 1.83 |
| Number of species captured | 12 | 24 |
| Total number of fish | 94 | 148 |
| Total weight of fish, g | 1,604.00 | 33,850.00 |
| Catch per effort, | | |
| Fish/hr | 59.50 | 80.90 |
| kg/hr | 1.00 | 18.50 |
| % gamefish | 16.00 | 41.90 |
| % panfish | 12.80 | 27.70 |
| % of gamefish desirable size | 6.70 | 24.20 |

[1] Data from backpack shocking of a shallow riffle downstream of the stilling weir is not included. Only boat electrofishing efforts are compared.

During late summer, the contrast can be even more extreme. In the 1970s, for instance, we had to drain the Mahoning Dam stilling pool for maintenance during the summer and conducted a fish salvage operation as the pool was reduced. In this entire 1.7-ha stilling pool, we only salvaged one walleye, one yellow bullhead, and about a hundred young of the year (<125 mm) yellow perch and bluegill. Meanwhile, anglers were successfully harvesting considerable numbers of large gamefish on the downstream side of the stilling weir during the pumpout.

So where did the District construct its Mahoning Creek Dam tailwater wheelchair access handicapped fishing pier? Unfortunately, it was placed above rather than below the stilling weir, where dangerously steep slopes could be avoided but where fishing is generally poor. With the knowledge gained from these studies, we are now able to more effectively locate such structures. For instance, in 1993 the initially proposed site for a handicapped access fishing pier in the Mosquito Creek Dam tailwaters was tentatively relocated from above to below that project's stilling weir, to provide improved fishing opportunities in spite of some increased logistical problems.

As was observed at Mahoning and Mosquito Creek dams, Jernejcic (1982a) similarly documented a paucity of fish upstream of the high Tygart Dam stilling weir relative to the more productive fishery downstream of its weir. However, it is essential to note here that stilling basins are definitely not necessarily areas with low concentrations of fish. In fact, if there is upstream fish access, it appears that these basins can be extraordinarily productive. At the Michael J. Kirwan Dam tailwater for example, where the weir is low and upstream movement of fish over the weir is possible, we found the majority of the sport fish in the tailwater concentrated among the concrete energy dissipating baffles within its stilling basin. With this in mind, in 1992 the District cut a small notch in the Conemaugh Dam stilling weir to allow for upstream movement of fish into its stilling basin where there is convenient fisherman access to the basin. Fish are attracted to the flow through the notch and can be frequently observed moving up through it. Fishing success is probably now nearly as good upstream of this modified weir as it is in the less accessible part of the tailwaters downstream of the weir.

Similar to the manner in which one-way downstream trips of fish over stilling weirs can influence the local abundance of fishes in tailwaters, the results of this study demonstrate an impact of low head water supply dams on the distribution of various species of fish across the upper Ohio River drainage basin. The issue here is principally that of recolonization by species that were totally extirpated from the entire upper Ohio River drainage during previous decades by uncontrolled domestic, industrial, and mineral extraction industry pollution.

The demise of assemblages of fish species from the region during the late nineteenth and most of the twentieth centuries, as a result of gross water quality degradation, was examined in detail by the Ohio River Valley Water Sanitation Commission (1962), Trautman (1981), and others. Species that could survive in smaller rivers and streams persisted in unpolluted refuge waters. However, those species that are primarily associated with large-river habitat such as sauger, spotted bass, drum, river and highfin carpsuckers, the buffalofishes, and paddlefish became locally extinct because of the pollution of the larger streams. Formerly, the water quality of five Corps of Engineers reservoirs and two large private utility hydropower reservoirs in the upper Ohio River drainage basin were so grossly degraded by acid mine drainage from bituminous coal mines that they were completely devoid of fish life, as were the entire Monongahela, Kiskiminetas, and Conemaugh rivers and thousands of miles of other local streams.

Beginning in the 1970s and continuing to the present, with improving water quality, fish began to invade and recolonize reclaimed waters. This restoration of local fisheries has been discussed by Preston and White (1978), Pearson and Krumholz (1984), and others. The first species to appear were those that had persisted in upstream water quality refuges. Recolonization by the previously mentioned large river species occurred later and apparently originated from sometimes remotely distant downstream areas from where they had to make multiple lockages up through the lock and dam structures of the Ohio River navigation system. This reintroduction process was deliberately facilitated, in cooperation with the Pennsylvania Fish and Boat Commission,

by operation of the eight navigation locks along the Allegheny River system. This was accomplished by first attracting fish into lock chambers with lock valve discharges, during the spring spawning season, and then conducting dummy upstream lockages. The primary target species of the operations was sauger. It took 8 years to reintroduce sauger above the furthest upstream project, and many non-targeted species also went along for the ride and were able to recolonize the middle and upper reaches of the Allegheny River.

Formerly extirpated species of fish are now showing up with increasing frequency in the reservoir tailwaters of projects in the Allegheny and Monongahela River basins, but are notably absent as a group from our Mahoning River basin reservoir tailwaters. Along the Beaver-Mahoning River, there are three low head water supply-hydropower dams of which two are currently generating, and along the Mahoning River proper there are 12 low head water supply dams. All of these 15 structures are apparently blocking or at least significantly delaying recolonization of the Mahoning River basin by formerly extirpated fishes now moving up through the Ohio River system.

## Summary

In spite of evidence usually apparent by the presence of concentrated populations of fish and fishermen in reservoir tailwaters, we believe that the enormous recreation angling potential of these fisheries has often not been fully appreciated by the Corps of Engineers and other resource management agencies. Research on and management of tailwater fisheries has been deficient, especially when compared with the levels of investment committed to reservoir fisheries.

The results of this study demonstrate the critical importance of local, regional, and even historical water quality to the development of high-quality reservoir tailwater fisheries. The results also provide some guidance for the design of weirs, access areas, and fish habitat structure such as tailwater embayments.

## Acknowledgments

Resource agency personnel from the States of Pennsylvania, Ohio, and West Virginia provided guidance and often direct assistance in the sampling program. Corps of Engineers resource managers and ranger staffs at all 16 reservoir projects sampled were very helpful in overcoming logistical problems and frequently offered direct assistance in the field efforts. The Hydrology and Hydraulics Branch of the Pittsburgh District Corps of Engineers provided optimal flow conditions and ensured that we were not washed out while working directly below the dams. In particular, we would like to thank J. Michael Fowles, Linda Stafford, Rosemary Reilly, and William Montgomery of the Pittsburgh District Corps of Engineers for their assistance in many different study aspects.

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# Water Quality Issues in the Central and Southern Florida Project

by
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## Introduction

One of the U.S. Army Corps of Engineers (USACE) (1987) water control management operating objectives is to maximize beneficial uses of the resource through enhancement and nondegradation of water quality. Viessman and Welty (1985) discuss the concept of "Total Water Management" where all aspects of the resource—quantity and quality—are considered, a program for maximizing the utility of the resource for the purposes it is dedicated to is formulated, interconnections between surface water and groundwater are considered, and the complete system is analyzed and optimized. House Document 90-369 pointed out that water quality control was a vital function in proper water resource management and would be incorporated in operational procedures of the Central and Southern Florida (C&SF) Project as may be dictated by results of continuing investigations in this area in cooperation with State and Federal agencies. Water quality regulations are a function of the State of Florida (USACE 1992a). A brief overview of some water quality issues in the Central and Southern Florida Project from a water manager's perspective will be discussed.

## Project Background

The C&SF Project is designed and constructed by the U.S. Army Engineer District, Jacksonville, and covers an area of about 15,000 square miles. Major features within the Project area include Kissimmee River Basin, Upper St. Johns River Basin, Lake Okeechobee and Outlets, East Coast Area, Everglades Agricultural Area, Water Conservation Areas, Everglades National Park, and Big Cypress National Preserve. The local sponsors for this project are the South Florida Water Management District (SFWMD) and the St. Johns River Water Management District (SJRWMD) for the Upper St. Johns River Basin portion. The Corps of Engineers operates and maintains project works on Lake Okeechobee and its outlets and the main outlets for the three Water Conservation Areas. The SFWMD and SJRWMD operate the remainder of the project based on Corps specified criteria. The Congressionally authorized project purposes include flood control, irrigation, municipal and industrial water supply, preservation of fish and wildlife, water supply to Everglades National Park, prevention of saltwater intrusion, recreation, and navigation. Water control plans and criteria for the project are developed by the Jacksonville District, in conjunction with SFWMD and SJRWMD, and must take into account the various, and often conflicting, project purposes (USACE 1987). SFWMD and SJRWMD are responsible for allocation of water from project storage except where mandated by Federal law. Some of the beneficial uses that have been identified specifically in legislation or later approved plans are water supply for municipal and industrial use, water supply for irrigation of agriculture, water supply for Everglades National Park, water supply for salinity control and dilution of pollutants in project canals, and water supply for estuarine management (USACE 1991b). In September 1993, the Department of Interior, Department of Commerce, Department of Army (Civil Works), Environmental Protection Agency, Department of Justice, and Department of Agriculture

[1] U.S. Army Engineer District, Jacksonville; Jacksonville, FL.

entered into an Interagency Agreement on South Florida Restoration to promote and facilitate coordinated Federal actions to restore the South Florida Ecosystem. This agreement established an Interagency Task Force and an Interagency Working Group to coordinate these efforts on ecosystem management among Federal agencies; State, local, and tribal governments; and the SFWMD.

## Upper St. Johns Basin

The Upper St. Johns Basin Project, currently under construction, is designed to provide flood control, water supply, and environmental enhancement. Water quality in the St. Johns River marsh will be improved by segregating agricultural discharges from the marsh (USACE 1991a). Interbasin diversions of water to the Indian River Lagoon will also be decreased.

## Lake Okeechobee

Lake Okeechobee is a large (about 740 square miles), shallow, subtropical lake with a marsh area of about 25 percent of the lake's surface (SFWMD 1993). According to the SFWMD (1993), Lake Okeechobee is comprised of a number of distinct ecological zones and has a high degree of interaction between its water and sediment. Maceina and Soballe (1990) pointed out that the interactions of wind, water level, circulation, nutrients, and algal dynamics in Lake Okeechobee are complex because of heterogenous spatial and temporal characteristics. Since significant water quality measurements were first documented in 1970, the phosphorus concentrations in Lake Okeechobee have increased steadily. Florida Department of Environmental Protection (DEP) and SFWMD have instituted measures to reduce the phosphorus loading to the lake. The Interim Action Plan (IAP), instituted by SFWMD in 1979 and formalized in the Lake Okeechobee Operating Permit (LOOP), has resulted in a 90-percent reduction in water backpumped to the lake through Pump Stations 2, 3, 4 (S-2, S-3, and S-4). Most of this water is now pumped in the Water Conservation Areas at Pump Stations 6, 7, and 8 (USACE 1991b).

The Florida Legislature passed the Surface Water Improvement and Management (SWIM) Act in 1987. The SWIM Act mandated the creation of a priority list of water bodies of regional and State significance, design and implementation of SWIM Plans for these water bodies, and creation of a SWIM trust fund (SFWMD 1993). The SWIM Act also specified phosphorus limitations for all tributary inflows to Lake Okeechobee. The limitations on tributary inflows were based on reaching an in-lake phosphorus reduction goal of 40 percent by July 1992 (SFWMD 1993). This recommendation was based on a modification of the Vollenweider nutrient-loading model as described by Federico et al. (1981). In 1988, SFWMD initiated a 5-year Lake Okeechobee Ecosystem Study with the University of Florida.

## Water Conservation Areas and Everglades

Prior to drainage, the Florida Everglades was up to 60 miles wide and stretched from Lake Okeechobee southward to the southern tip of the State between Florida Bay and the Ten Thousand Islands area. The Everglades Agricultural Area (EAA) is a large (about 1,100 square miles), highly productive agricultural area comprised of organic peat or muck soils south of Lake Okeechobee. The three Water Conservation Areas (WCAs), located south and east of the EAA and west of the urbanized East Coast, comprise an area of about 1,350 square miles. The three WCAs make up a large segment of the original Everglades. Water Conservation Area No. 1 is designated as the Arthur Marshall Loxahatchee National Wildlife Refuge. Water Conservation Areas No. 2 and 3 are public hunting and fishing areas; they comprise the Florida Game and Fresh Water Fish Commission Everglades Wildlife Management Area. The effects of the regulation schedules on fish, wildlife, and vegetation in the WCAs were and are important considerations in determining regulation schedules shapes and ranges (USACE 1992a). Everglades National Park lies south of the WCAs, covers about 2,200 square miles, and

consists of five major physiographic subzones: Shark River Slough, Rocky Glades, Broad River/Lostmans River, Coastal Swamps and Lagoons, and Cape Sable (SFWMD 1993).

According to Davis et al. (1987), the Everglades is viewed as an ecosystem that evolved under very limited nutrient supplies where minor increases in nutrient supply have been observed to have major ecosystem impacts, and that nutrient supply to the Everglades has increased primarily as the result of drainage of the EAA runoff into the Water Conservation Areas and ultimately Everglades National Park (ENP). Nearhoof (1992) reports that research indicates that Everglades sawgrass and slough communities prefer low-nutrient levels, prolonged hydroperiods, shallow-water depths, and 3- to 10-year burn intervals, followed by gradual reflooding. The Everglades SWIM Plan (SFWMD 1992) states that since drainage systems were constructed within the EAA, surface water runoff from that area has contained high concentrations of nitrogen and phosphorus resulting from soil subsidence and use of phosphorus fertilizers and also contain high concentrations of dissolved minerals.

## Everglades National Park

Public Law 91-282 provided for a minimum monthly delivery schedule of water from the C&SF Project to Everglades National Park at Shark River Slough, Taylor Slough, and the Eastern Panhandle. Senate Document 91-895, which accompanied the law, pointed out that while the legislation is designed to ensure an adequate supply of water to ENP, in order to preserve the park's unique ecosystem, it is important that consideration be given to the quality of the water delivered. The Corps and the National Park Service (NPS) were to reach an early agreement on measures to ensure that the water delivered to ENP was of sufficient purity to prevent ecological damage or deterioration of the park's environment. This led to the Memorandum of Agreement (MOA) among the Corps of Engineers, SFWMD, and NPS for the purpose of protecting the quality of water entering Everglades National Park.

This MOA provides for specific numerical water quality criteria for ENP water deliveries for a number of parameters such as dissolved oxygen, nutrients, major ions, trace metals, and pesticides.

## Saltwater Intrusion

The Biscayne Aquifer underlies much of Dade, Broward, and southern Palm Beach counties. It is a surficial, highly permeable, wedge-shaped aquifer that is about 200 ft thick at the coast but thins to a few feet near its western boundary 35 to 40 miles inland. This aquifer provides water for municipal and industrial (M&I) water supply and agricultural irrigation along the southeast coast. Water supply releases can be made from the Water Conservation Areas, or transferred from Lake Okeechobee, to the coastal areas to prevent saltwater intrusion and recharge the surficial aquifer (USACE 1992a). Inland movement of salt water in tidal canals and streams is basically a function of the relative densities of fresh water and salt water, the rates of freshwater discharge, and tidal action (Hughes 1979). The coastal spillways prevent a saltwater wedge from moving up the canals and maintain sufficient freshwater head to prevent saltwater intrusion in the aquifer.

The City of Fort Myers and Lee County have municipal water intakes in the Caloosahatchee River (Canal 43) upstream of Structure 79 (S-79). During low-flow periods, operation of Franklin Lock at S-79 permits a saltwater wedge to move upstream. When the chloride content of water upstream of S-79 approaches the drinking water standard of 250 mg/L, a large, short-duration release is made from Lake Okeechobee to flush through the spillway the saline water that had accumulated upstream of the lock (USACE 1991b). Algal blooms, which cause taste and odor problems at the water treatment plants, have occurred in the Caloosahatchee River during drought periods. Short, high-rate discharges are made from Lake Okeechobee to flush the algal blooms downstream. During declared water shortages, lockages at Okeechobee

Waterway navigation locks can be restricted to conserve fresh water and reduce saltwater intrusion (USACE 1991b).

## Estuarine Impacts of Freshwater Releases

Estuarine areas are impacted by freshwater releases from the C&SF Project. For example, regulatory releases from Lake Okeechobee are made through the St. Lucie Canal and the Caloosahatchee River. Large regulatory releases adversely affect the salinity regime in the St. Lucie and Caloosahatchee estuaries. There have several revisions to the Lake Okeechobee regulation schedule aimed at reducing the frequency, duration, and severity of regulatory releases on these estuaries. A key component is a series of zones of moderate regulatory releases with stepped increases in discharge rate that reduces the frequency of large, damaging releases (USACE 1992b). Another important technique currently being tested is the use of pulse releases from Lake Okeechobee that mimic the pulse releases associated with a rainfall event (SFWMD 1993). Estuarine areas, such as Florida Bay, have also been impacted by reductions of freshwater flow (SFWMD 1993). The Modified Water Deliveries to Everglades National Park Project, Canal 111 General Revaluation Report, and Taylor Slough Demonstration Project are examples of projects that could help improve freshwater flows.

## Water Quality Litigation

In October 1988, the United States filed suit against the State of Florida Department of Environmental Regulation (DER) and the SFWMD alleging violation of Florida environmental laws by diverting nutrient-polluted waters through the C&SF Project to the detriment of Arthur J. Marshall Loxahatchee National Wildlife Refuge (WCA No. 1) and the Everglades National Park and by failing to enforce its environmental laws against the sources of pollution. In full recognition that the Park and Refuge are unique and irreplaceable natural resources, and in order to settle the lawsuit, the Federal and State parties agreed in July 1991 to cooperate in a commitment to restore and maintain the quality of water delivered to the Park and Refuge (USACE 1992a). Under the terms of the agreement, the Corps agreed to apply for storm-water management permits for the operation of the Structures 10, 11, and 12 (S-10, S-11, S-12) and that new structures are designed and constructed by the Corps in a manner consistent with the Settlement Agreement. The Corps of Engineers agreed to cooperate in modification of its regulation of the C&SF Project in order to support the objectives set forth in the Settlement Agreement. A Technical Oversight Committee (TOC), consisting of representatives from the SFWMD, Department of Environmental Protection, National Park Service, U.S. Fish and Wildlife Service, and the Corps of Engineers, was established to plan, review, and recommend research, monitoring, and compliance conducted pursuant to the Settlement Agreement. The Settlement Agreement established interim and long-term Total Phosphorus limits for ENP and Loxahatchee National Wildlife Refuge. The State agreed to construct Stormwater Treatment Areas (STAs) to provide nutrient removal of water discharged into the Everglades Protection Area and implement regulatory programs requiring Best Management Practices (BMPs).

A number of challenges and appeals to the Settlement Agreement were filed. In July 1993, the State and Federal Government, SFWMD, and certain agricultural interests agreed to a Statement of Principles outlining a framework for a mediated Everglades Cleanup and Restoration Plan. A Mediated Technical Plan was developed; however, at this time (February 1994), mediation has ended and litigation has resumed.


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# A State and Federal Partnership for Water Quality Investigations for Two Southeastern River Basins

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## Background

The States of Alabama, Georgia, and Florida have numerous surface and groundwater resources that appear to sustain almost limitless water availability. These water resources and the abundant rainfall in the Southeast provide these States with an unbounded capacity to use water for navigation, municipal and industrial water supply, recreation, agricultural and aquacultural uses, water quality, and fish and wildlife conservation practices. Or so many people thought until the 1980s.

When a searing series of droughts occurred during the 1980s, the thoughts of unlimited water availability evaporated. The reality of having to support ever growing demands for water from a finite supply became evident to many people in these southeastern States. This was especially true in two river basins, the Apalachicola-Chattahoochee-Flint (ACF) and the Alabama-Coosa-Tallapoosa (ACT). The ACT basin is located in Georgia and Alabama, and the ACF basin is located in Florida, Georgia, and Alabama. The basins have a combined drainage area of 42,400 square miles and contain several growing metropolitan areas including Atlanta, Columbus, and Rome, GA, and Montgomery and Dothan, AL. The largest growth has occurred in the city of Atlanta. Located in the headwater portions of both basins, Atlanta and its metropolitan area have experienced a population increase from less than one-half million in 1950 to almost three million in 1990 (U.S. Department of Commerce 1991).

This growth and the reality of finite water resources forced the States, primarily the State of Georgia, to look at many methods to meet demands. These means included, in part, construction of main stem and tributary water supply reservoirs, as well as requesting reallocation of water storage in Federal reservoirs from other uses such as hydropower and navigation to water supply. There are 10 Federal impoundments and 21 non-Federal impoundments within the two basins. The multipurpose Federal reservoirs were constructed and are operated by the U.S. Army Corps of Engineers. The non-Federal reservoirs were constructed by power companies and other industries primarily for hydropower production, although some municipal water needs are supplied from these reservoirs.

Because of the increasing growth and demand for water in the upper end of the two basins, downstream water users in all three States became increasingly concerned with actions being taken and actions being considered to meet water demands. In the late 1980s, municipalities and governmental agencies in the upper portions of these basins requested the reallocation of storage in several nearby Federal reservoirs from other uses to municipal and industrial water supply. In 1989, the Corps produced several reallocation reports that evaluated the changes from hydropower storage to water supply storage. These reports considered the changes in storage from economic standpoints for the National Economic Development Plan and from environmental assessments in National Environmental

1 U.S. Army Engineer District, Mobile; Mobile, AL.
2 Formerly U.S. Army Engineer District, Mobile; presently ENSERCH Environmental Corporation, Huntsville, AL.

Policy Act (NEPA) documents. Within 12 months of these efforts to gain access to water in Federal reservoirs, the State of Georgia announced plans to construct a water supply reservoir and requested a Section 404(b) permit from the Corps to construct the reservoir on the headwaters of the Tallapoosa River in west Georgia.

The State of Alabama, increasingly concerned with potential water quality changes that could occur with these proposed actions, filed suit in June 1990 challenging the adequacy of the NEPA documents evaluating the reallocation requests. The State of Florida became disturbed about the potential effects that upstream water-use changes could have on Lake Seminole on the Chattahoochee River and on the Apalachicola River and Bay. An already charged atmosphere among the States of Alabama, Georgia, and Florida and the Corps became antagonistic. With this volley fired by the State of Alabama, the water-use conflict became known in the media as the "Water Wars." This paper describes a consensus or partnership approach to water-management studies, particularly water quality studies being taken by these three southeastern States and the Corps of Engineers that developed out of this litigation.

## Study Initiation

In July 1990, discussions began between the States of Alabama and Georgia, with Florida and the Mobile District Corps of Engineers joining later to try to resolve the dispute. Negotiations centered on the immediate water needs within the two ACF and ACT river basins and an acceptable method to address long-term water resource needs within these basins. An expanded role for the States in water resources planning and decision making was necessary for successful resolution of the dispute. While these negotiations were underway, the State of Alabama was granted its request to have the litigation placed on an inactive docket.

To assist in the resolution of this conflict, Congress funded, in Fiscal Year 1991, a Comprehensive Study (the Study) for these river basins to develop the needed basin and water resource data and to recommend an interstate mechanismfor resolving water-use issues. The authorizing language from Congress expressed the intent that:

> "This study will evaluate the long-term water resources availability and needs within the two river basins. When complete, this study will provide the Governors of the three States with the information they need to develop a mutually agreeable plan for the allocation of available water in the basins..."[1]

Clearly the congressional desire was to establish a mechanism to allow interstate management of the water resources from a basin-wide context. However, the States contended that this Federal study would not provide a dispassionate analysis of the water needs and would not consider each State's respective views and interests in developing a solution for equitable allocation of available water. This contention was resolved when all three States agreed to participate in the study not as advisers to the Corps, the Federal agency conducting the study, but as full partners on a consensus basis. This approach to participation requires that decisions are made by unanimity of all four Study partners, a process that takes considerable negotiation and, at times, considerable diplomacy. The States further agreed to show support for the congressionally authorized study by providing State funds to supplement the Federal monies.

On January 3, 1992, the Governors of Georgia, Alabama, and Florida and the Assistant Secretary of the Army for Civil Works signed a Memorandum of Agreement (MOA).

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1 Energy and Water Development Appropriations Act, 1991, Public Law 101-514, November 5, 1990.

The MOA confirmed the negotiated agreement by specifying that the parties would participate in the Study as equal partners, that the States would contribute direct and indirect monetary resources, and that a best effort would be made to complete the Study in three years. The MOA stated that the purposes of the Study are to learn the capabilities of the water resources, to describe the water resource demands of the basins, and to evaluate alternatives that use the water resources to benefit all user groups within the basins. The Study will focus on providing a good technical understanding of the water resources in the basins and in defining alternative ways to equitably allocate the use of water in the basins. The Study will identify the needs and potential solutions through the year 2050.

## Study Management

Management of the Study is conducted by a hierarchial organization headed by the Executive Coordination Committee (ECC). The ECC, composed of representatives appointed by the three Governors and the Assistant Secretary of the Army (Civil Works), provides overall administrative management to the Study. These members, considered the principal partners, have appointed designees on the Technical Coordination Group (TCG). The TCG provides the day to day technical management of the Study, accomplishing Study design, and recommending specific decisions on study matters to the ECC for approval. The TCG is advised in technical Study matters by Technical Support Groups (TSGs). The TSGs are composed of representatives from all Study partners with expertise or interest in particular areas. For example, on water quality matters, the TCG is advised by a TSG called the Water Quality Task Force. The Water Quality Task Force is composed of State water quality officials, a representative from the U.S. Environmental Protection Agency, and a Corps of Engineers water quality specialist. Using this concept of technical advisers from all Study partners, the TCG, in conjunction with TSGs, has developed a Plan of Study to accomplish the Study.

The 17 elements of the Plan of Study are grouped into three major categories reflecting the areas of emphasis (The Comprehensive Study Technical Coordination Group 1992). The categories are water demand, water resources availability, and comprehensive management strategy. The purpose of the water demand element is to identify, describe, and quantify all water demands within the basins. Specific areas associated with the water demand element are demands within agriculture, the freshwater needs of the Apalachicola River and Bay, the environment, hydropower, industry, municipalities, navigation, recreation, and waste assimilation. Water resources availability will examine the factors that influence the availability of water resources and will include both groundwater and surface water supply. The comprehensive management strategy study element includes the basinwide management program that will examine all water resource use alternatives developed, evaluate these alternatives through various means including models, and select alternatives for recommendation to the ECC; the institutional framework analysis that will identify existing laws, regulations, and/or policies of the Study partners that could constrain or prevent developing an interstate coordination mechanism; and the coordination mechanism program that will recommend an instrument or procedure for interstate water resource management. Specific scopes of work for each of the Study elements have been developed and work is underway.

Aspects of water quality were originally covered in two separate elements, the Environmental Demand Element and the Waste Assimilative Capacity Demand Element. For expedience and efficacy, the Water Quality Task Force recommended combining the water quality aspects of these elements into a separate Water Quality Element. The TCG agreed and this has been done. Described below is the Water Quality Element as presently agreed to by all Study partners.

## Water Quality Element

The Water Quality Element now consists of three subelements: a water quality inventory and summary; a basinwide one-dimensional water quality model; and two-dimensional water quality models at three selected reservoirs in the ACF/ACT basins. Presently, the study partners are also evaluating additional data collection and subsequent water quality modeling for Lake Seminole on the Chattahoochee River.

### Water Quality Inventory and Summary

The objectives of the water quality inventory and summary subelement are as follows: to inventory, collect, compile, and summarize the existing relevant data on water quality in both basins; to identify the usefulness of the data collected; and to identify major data gaps for subsequent water quality modeling. Water quality data inventoried will include surface and groundwater water quality, fish flesh, and toxics and nutrients (nitrogen and phosphorus species) in sediments.

This subelement consists of two phases. The inventory phase will include the inventory and compilation of existing relevant water quality and quantity data, information on water quality standards and main stem cross-sectional stream geometry data. The assessment/summary phase will involve the analysis of the water quality data to characterize the basins' water quality and to identify water quality trends, critical areas of water quality concerns, areas where additional data collection may be necessary to characterize the basins' water quality, and data gaps for subsequent water quality modeling.

### Basinwide One-Dimensional Water Quality Model

The objective of this subelement is to develop an integrated, calibrated, basinwide one-dimensional water quality model suitable for analyzing and addressing many water quality concerns of the ACF/ACT basins, and in turn, evaluating various system operation alternatives designed to mitigate existing and anticipated water quality problems.

The modeling tool selected to do this portion of the study is the U.S. Army Corps of Engineers HEC-5Q model. This model is a generalized computer program design to simulate flow and water quality within a branched stream and reservoir system. All stream and reservoir components will be simulated sequentially within a single run, thereby eliminating the need to separate simulation of reservoir and stream systems with file interfaces. The model will represent components of the system one dimensionally providing computed vertical or longitudinal profiles of water quality in reservoirs and longitudinal water quality in stream sections of both basins.

The HEC-5Q model offers both a standard and an enhanced version. The standard version of HEC-50 has two basic water quality parameter options. Under option one, temperature, up to three conservative (concentration directly related to extent of dilution and not affected by decomposition, chemical alteration, or physical removal as a result of natural processes) and three nonconservative water quality parameters and dissolved oxygen may be simulated. If dissolved oxygen is simulated, the first nonconservative parameter must be biological oxygen demand (BOD). A second nonconservative parameter may be utilized if the simulation of carbonaceous and nitrogenous BOD is desired. Each conservative parameter may represent particulate matter by assigning settling rates. Under option two, temperature, one conservative parameter, carbonaceous BOD, plant nutrients (ammonia nitrogen, nitrate nitrogen, and phosphate), phytoplankton, and dissolved oxygen are simulated. The enhanced version of HEC-5Q includes several additional water quality parameters such as pH, alkalinity, total inorganic carbon, suspended sediment, and pollutants such as heavy metals and organic chemicals. The enhanced version also includes a more comprehensive phytoplankton model.

The objectives of the basinwide one-dimensional water quality model subelement will be accomplished in several phases. The sequential completion of each will transform the existing HEC-5Q program and raw data sets into a fully documented program and a calibrated model representation capable of evaluating the water quality responses within the ACF/ACT basins. Model evaluation of the proposed system operation policies and change scenarios will quantify the potential immediate and long-term effects of each alternative.

### Two-Dimensional Reservoir Water Quality Modeling

The Water Quality Task Force felt there were several reservoirs within the two basins that, because of existing or potential water quality issues, would need more spatially detailed analyses of the water resource use alternatives than could be provided by the HEC-5Q model. Thus, a two-dimensional model subelement was initiated with the objective of providing calibrated and verified two-dimensional (2D) water quality models for Lakes Weiss and Neely Henry in the upper ACT basin and Lake Walter F. George in the lower ACF basin. These models will be capable of predicting future water quality conditions resulting from water resource use alternatives such as changes in upstream water allocations, upstream waste loads, and/or system operations.

CE-QUAL-W2 is a widely recognized state-of-the-art longitudinal and vertical hydrodynamic/water quality model. Because of its capabilities and because of its use in other studies, the Study partners selected it for this study. The model contains a hydrodynamic portion that predicts water surface elevations and horizontal and vertical velocities. The predicted velocities are used for transporting constituents in the water quality module. The hydrodynamics are influenced by variable water density (i.e., stratification) resulting from variations in temperature, salinity, or total dissolved solids and suspended solids. The transported state variables and their kinetic interactions to be used in the water quality module will be selected after the water quality inventory is completed.

The Study partners also felt it necessary for the 2D model to simulate algal/nutrient interactions for this Study. CE-QUAL-W2 includes options for specifying sediment oxygen demand (SOD) or simulating SOD through the organic sediment state variable and associated kinetic compartments. The Study partners anticipate using the simulated SOD approach for predicting future water quality conditions as influenced by changes in waste loads brought about by various water resource use alternatives. Oxygen demand predicted by the calibrated water quality model will be compared with measured values wherever possible.

## Study Future

Work on the Water Quality Element, as well as the other 16 elements of the ACF/ACT Comprehensive Basin Study, is well underway. The Study partners are planning to have much of the technical information for the Study developed by early 1995. To meet this goal, the Study partners have devoted considerable time and effort into planning all elements of the Study. This has required much give and take by all partners to develop the specific workplans for the Study. Reaching the Congressionally mandated goal of developing "mutually agreeable plans" for water use in the ACF and ACT basins still continues to provide challenges and opportunities for all partners.

Congress recently reaffirmed the potential of this consensus or partnership approach to water resource planning and its concomitant potential for success. Language in the Fiscal Year 1993 Appropriations Bill states that the Study:

> "...could serve as a model for management of future basin studies and basin

management plans, as well as a model for Corps and State cooperation. This process represents a commitment to balanced use development and protection of the water resources in both basins ..."[1]

Consensus planning by State and Federal partners, though requiring careful maneuvering around the rocky shoals of contention, provides a promising way to address complex and diverse water resource issues and a potential for smooth sailing in the interstate uses of waters in the future.

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1 Energy and Water Development Appropriation Bill, 1993, Public Law 102-377, October 2, 1992.

# Corps Role in Nutrient Reduction to Everglades National Park

*by*
*James J. McAdams*[1]

## History

During the expansive growth of South Florida from the 1900s to the present, water resources problems have multiplied in South Florida. This is due to expansion of population and agriculture in the rich Everglades soils south of Lake Okeechobee (see Figure 1). Originally, the area just above and below Lake Okeechobee called the Everglades and now including the Everglades National Park was undeveloped except for the east coast Miami/Palm Beach/Fort Lauderdale area. The Florida Everglades was once described as a "river of grass" up to 60 miles wide stretching from Lake Okeechobee southward to the southern tip of the State near Florida Bay. Before levee development and works of man began, there was no well-defined outlet from Lake Okeechobee to tide water. During prolonged wet periods, Okeechobee would overtop its southerly banks and flow into the northern Everglades. Some of the overflow water proceeded westward while other flows went eastward to the ocean by way of natural streams and sloughs. Most proceeded south in the Everglades trough.

In the late 1800s, there was a great deal of interest in draining the Everglades to spur a new agricultural industry in Florida. However, it wasn't until the 1920s that people now living in South Florida, and the developers, began drainage projects in order to use the areas for agriculture. The first work done in South Florida was undertaken by private interests. The developer/entrepreneur Hamilton Disston acquired 4,000,000 acres of land from the State at $.25 per acre and began drainage efforts in 1882. He connected Lake Okeechobee and the Caloosahatchee River to provide Okechobee an uninterrupted outlet. Disston also constructed and improved numerous canals in the Kissimmee River Basin.

The Everglades Drainage District was established by the State in 1907 to direct development. By 1929, over 400 miles of canals had been constructed in the Everglades, 16 spillways or locks, and 50 miles of levee around the southern part of Lake Okeechobee. Major canals provided were St. Lucie, West Palm Beach, Hillsboro, North New River, South New River, and Miami Canals. The primary aim of the Everglades Drainage District was to permit land development to be accomplished by drainage and flood protection with canals draining excess water to the coast. All work, up to that time, was non-Federal.

By 1925, South Florida had a population of about 250,000. Approximately 256,000 acres of former Everglades were being utilized for agricultural production around the south shore of Lake Okeechobee.

The Federal Government and the Corps first became involved with flood control in South Florida following major hurricanes in 1926 and 1928. Almost 3,000 people were killed in South Florida during these hurricanes from water flowing out of Okeechobee. A previously authorized Corps navigation project was modified in 1930 to include about 87 miles of levee around parts of Lake Okeechobee and six hurricane gate structures for flood protection.

[1] U.S. Army Engineer District, Jacksonville; Jacksonville, FL.

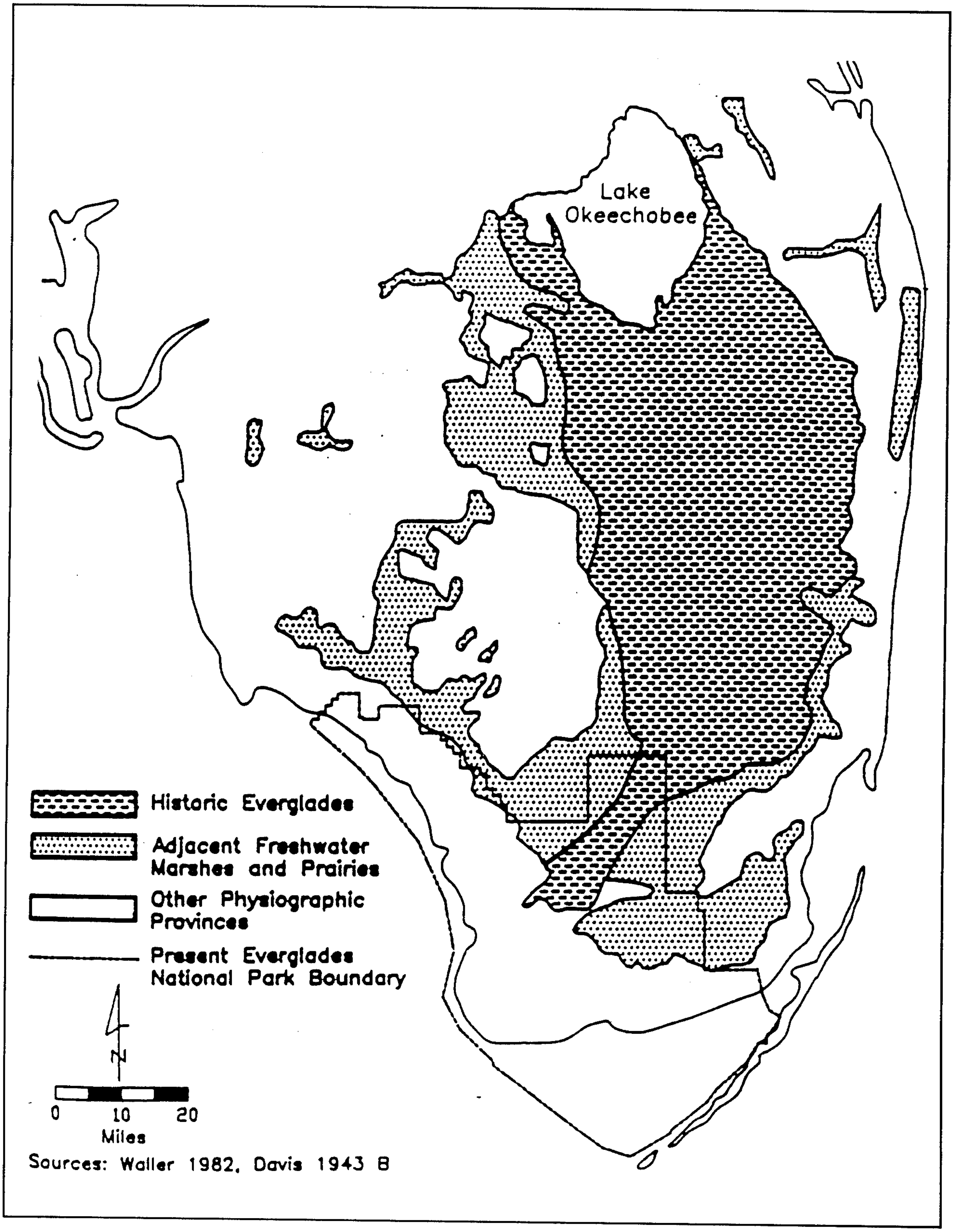


*Figure 1. Boundaries of the historical Everglades Basin*

## Problem Areas

The project undertaken by the Corps is now labeled the Central and Southern Florida Flood Control Project (C&SF) (Figure 2). The Corps and the local sponsors, the former Everglades Protection District, now called the South Florida Water Management District (SFWMD), built or refined a massive system of canals and water management structures operated cooperatively by the Corps and the South Florida Water Management District. The C&SF Project covers an area of about 15,000 square miles and contains about 1,000 miles of project levees, about 1,000 miles of project canals, 30 project pump stations, and over 200 project water control structures.

The hydrology and hydraulics of the C&SF Project are affected by the flat hydraulic gradients, indeterminate drainage divides, periods of extremely intense rainfall, high evapotranspiration rates, overland sheet flow, subsurface flow, and occurrence of hurricanes. During the 1930s, several problems with the drainage system became apparent. Several well fields in the Miami area "salted up" as a result of a lack of saltwater barriers in coastal canals. Muck fires became a major problem during several drought years as well as subsidence of the muck soils. When the rich Everglades muck is exposed to air, microorganisms oxidize the organic material (Nearhoof 1992).

Because of both drainage and levee construction, the Everglades National Park was denied its natural historic shares of surface water flows resulting in severe damage to plants and animals. Because of these well-publicized water quantity problems of the 1960s, the United States Congress through its Committee on Public Works guaranteed to the Park a minimum annual delivery. In addition to establishing a monthly surface water delivery, the question of water quality was also addressed. A document was published as a result of discussions in the 91st Congress, 2nd Session, requiring the Corps and the National Park Service to reach an early agreement on measures to ensure that the waters delivered to the Park be of sufficient purity to prevent ecological damage or deterioration of the parks environment (Rosendahl and Rose 1979).

The Corps acknowledged that the quantity and quality of the system were interdependent. All agencies working in the area would have to begin to adjust the system to operate to preserve the biological resources of the area.

## Tools for Change

The Corps' role in water quality for South Florida is now supported by three main vehicles. The first vehicle being the House Documents mentioned previously instructed the Corps and the Everglades National Park to reach agreements to ensure the quality of water to the Park. This agreement established a Memorandum of Agreement and a water quality sampling program between the Corps, the Everglades National Park, and the South Florida Water Management District and resulted in several studies to assess and ensure the quality of the water being delivered to the park. However, the large water management areas in the upper part of the Everglades were only peripherally included.

The second vehicle was given through a 1988 lawsuit by the U.S. Department of Justice to force the State of Florida and the South Florida Water Management District to enforce State water quality standards. The United States filed suit against the State of Florida (the State Department of Environmental Regulation and the South Florida Water Management District) alleging violations of Florida environmental laws. It was charged that allowing diversion of nutrient-enriched waters through the C&SF project contributed to the detriment of the Loxahatchee National Wildlife Refuge (LNWR) and the Everglades National Park (Park). In order to settle the lawsuit, in July of 1991, the Federal and State parties agreed to cooperate in a signed Settlement Agreement to restore and maintain the quality of water delivered to Loxahatchee and the Park.

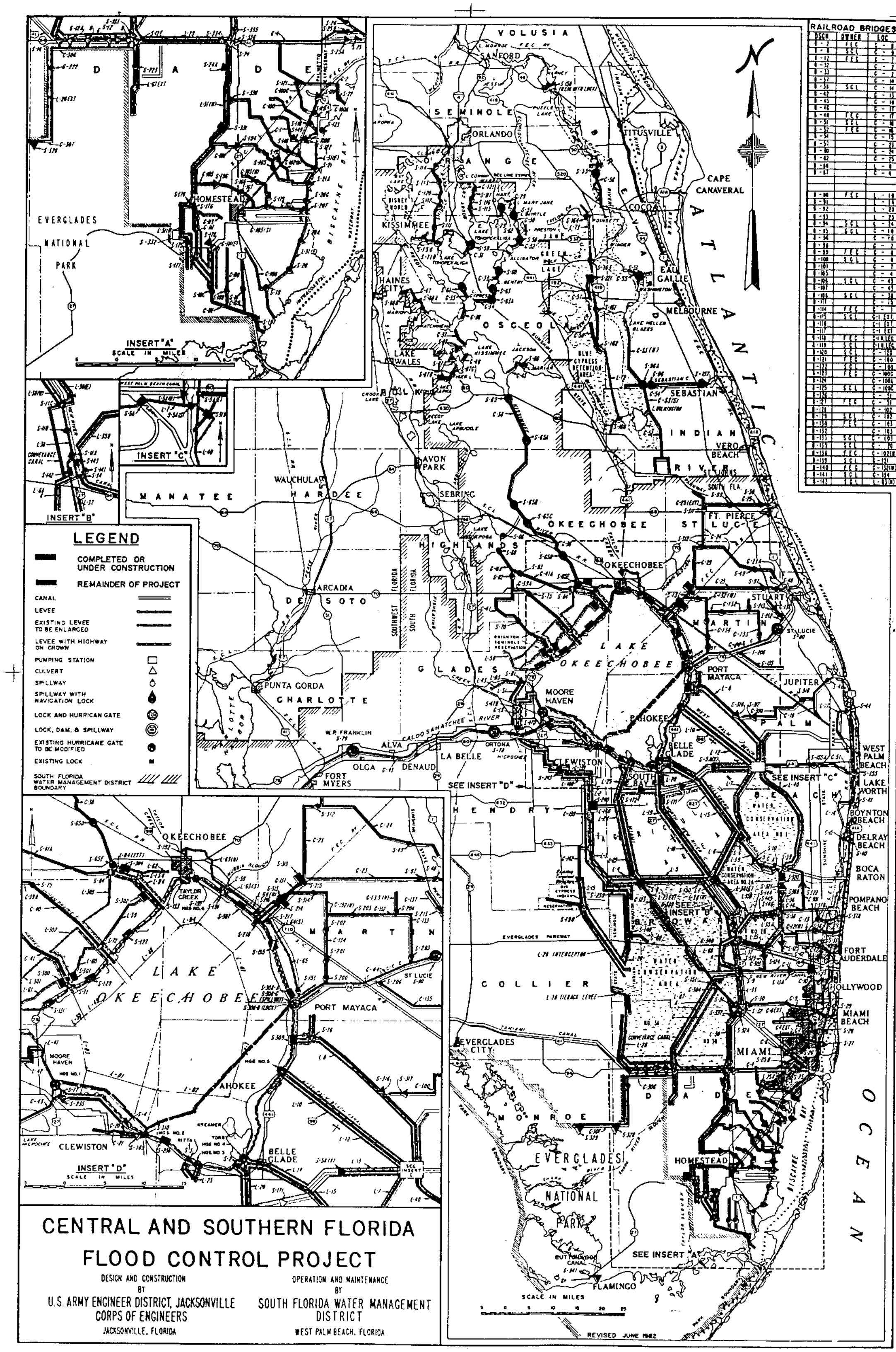


*Figure 2. Central and Southern Florida Flood Control Project*

The Corps also has a third vehicle through its limited authority to improve the quality of the water through its projects as mitigation. The following national policy statements are relevant. It is national policy (EO 12088, 13 October 1978, 3 CFR) that the Federal Government, in the design, construction, management, operation, and maintenance of its facilities, shall provide leadership in the nationwide effort to protect and enhance the quality of our air, water, and land resources. The Clean Water Act and the National Environmental Policy Act also require water quality evaluations prior to construction of a Federal project. Internally, ER 1130-2-334, ER 1130-2-415, and CESA-DR 200-2-1 all require evaluations of existing water quality at Corps projects.

Additionally, a significant study giving impetus to water quality improvement through the Corps works also came from the State of Florida in 1992, proving that there were violations of water quality criteria in the Everglades and in the water bodies downstream of the structures that are controlled by the Corps. It was apparent that the Everglades ecosystems characterized by marshy plains and sparse vegetation were being replaced by cattail growth and other high nutrient species. Review of available data and literature showed that phosphorus-enriched water discharged from Everglades agricultural areas, to protected Everglades areas, and eventually the Everglades National Park had caused or contributed to at least four major widespread violations of Florida water quality criteria. These were (a) imbalances of aquatic flora and fauna, (b) dominance of nuisance species, (c) change in biological integrity, and (d) dissolved oxygen problems (Nearhoof 1992).

The communities most directly affected were identified as microbial decomposers, periphyton, macrophytes, and macroinvertebrates (Swift). Through food web changes and alteration of the physical and chemical characteristics of the habitat, the fish, waterfowl, wading birds, and other higher organisms are also felt to have been affected.

Given these tools to try to achieve the goals of water quality improvement or degradation prevention, there are still some procedural and conceptual constraints. The Corps, while being a water management agency, has little control over the quality of the water being delivered to its structures. The quality has to be improved on the land prior to entrance into the system.

## Settlement Agreement

The State of Florida and the Federal Government through the Settlement Agreement and the enactment of the Marjorie Stoneman Douglas Act concurrently in the State Legislature, finally settled the water quality lawsuit with a Settlement Agreement setting a water quality improvement strategy that includes the following components:

*a.* The construction and operation by the State of stormwater treatment areas (STAs), large wetland treatment systems that will process storm runoff for the removal of nutrients.

*b.* The implementation of a State regulatory program requiring the reduction of the present total phosphorus loads from the Everglades agricultural area to each STA by 25 percent using best management practices and controlled development in the Everglades agricultural areas.

*c.* The initiation of a long-term multiagency research and monitoring program designed to numerically define the appropriate water quality standards and assess the current responses of the protected Everglades to nutrient input levels.

*d.* The Corps and South Florida Management District would apply for Operating permits for the structures they owned and operated and new structures would be built in a manner consistent with the agreement. The document

was signed with the understanding that any permit terms be reasonable and related to alleviating water quality problems, and also within the limits of Corps congressional authorizations for water supply and flood control.

*e.* The Corps would cooperate in modification of the regulation schedule for the C&SF project in order to support the objectives of the Settlement Agreement.

The Settlement Agreement provides a framework by which the Corps, the Everglades National Park, the South Florida Water Management District, and the State of Florida can cooperatively assist in implementing measures necessary for improvement of the quality of water in South Florida. They can also cooperate in setting the nutrient standards that are needed to determine what should and should not be dumped into the Everglades and eventually Everglades National Park through the structures.

When it is found that the quality of the water delivered south through the entire C&SF project is not sufficient to meet the standards, then the water will be processed through STAs (Figure 3) to be built by the State.

The State's portion of the Settlement Agreement project will include building six large STAs totaling over 33,000 acres to intercept waterborne pollutants before they can reach the sensitive Everglades wetlands ecosystem and the Park (Burns and McDonnell 1992). These large marsh flowways will be managed with species of plants that will remove nutrients of concern from the water flowing through them. The systems will function as natural wetland treatment areas, and the hydraulic loading of each treatment area will be constrained by the need to control depth, velocities, and hydraulic retention times to maintain plant species within each cell of the treatment area, promote microbial communities in the litter zone, and to provide sufficient contact time for nutrient uptake. The principal pollutant of concern, total phosphorus, should be stripped from the water as it flows southward through the STAs from the Everglades agricultural areas towards the more protected Everglades areas to the south.

The present design of the State STA uses calculations based on a measured settling rate constant of 10.2 m per year to remove phosphorus concentrations from receiving waters. This is to achieve a long-term flow weighted average phosphorus concentration of 0.05 mg/L at each point of discharge to the protected Everglades areas (Walker 1993). The removal rates were generated from an extensive evaluation of water conservation area 2A, which over the past 30 years has essentially operated as an STA removing nutrients from inflows through the S-10 structures and pump station S-7. Estimated phosphorus loads through the various pump stations for the period January 1979 through September of 1988 were furnished by reporting the total phosphorus loads in kilograms at each station. These data were then coupled with historic monthly discharges from each of the stations, resulting in a listing of average monthly phosphorus concentrations for the period of record. The recommended size of the area was then calculated.

The STAs will be pulse driven. Rain events will generate runoff, which will be directed to the artificial wetland by gravity or pumping as is generally the case now for the water conservation areas. However, pumping schedules will not be the same for any two wetlands present or planned. The quantity and quality of the pumped water inputs will be dynamic on both a long- and short-term basis and will include direct rainfall inputs and evapotranspiration. The sites will be designed as large retention areas with several interior flow cells and flowways. The design and operating schedule for the outflow structures combined with the time-varying inputs will produce a variable storage within the STAs and the interior cells. Great care will

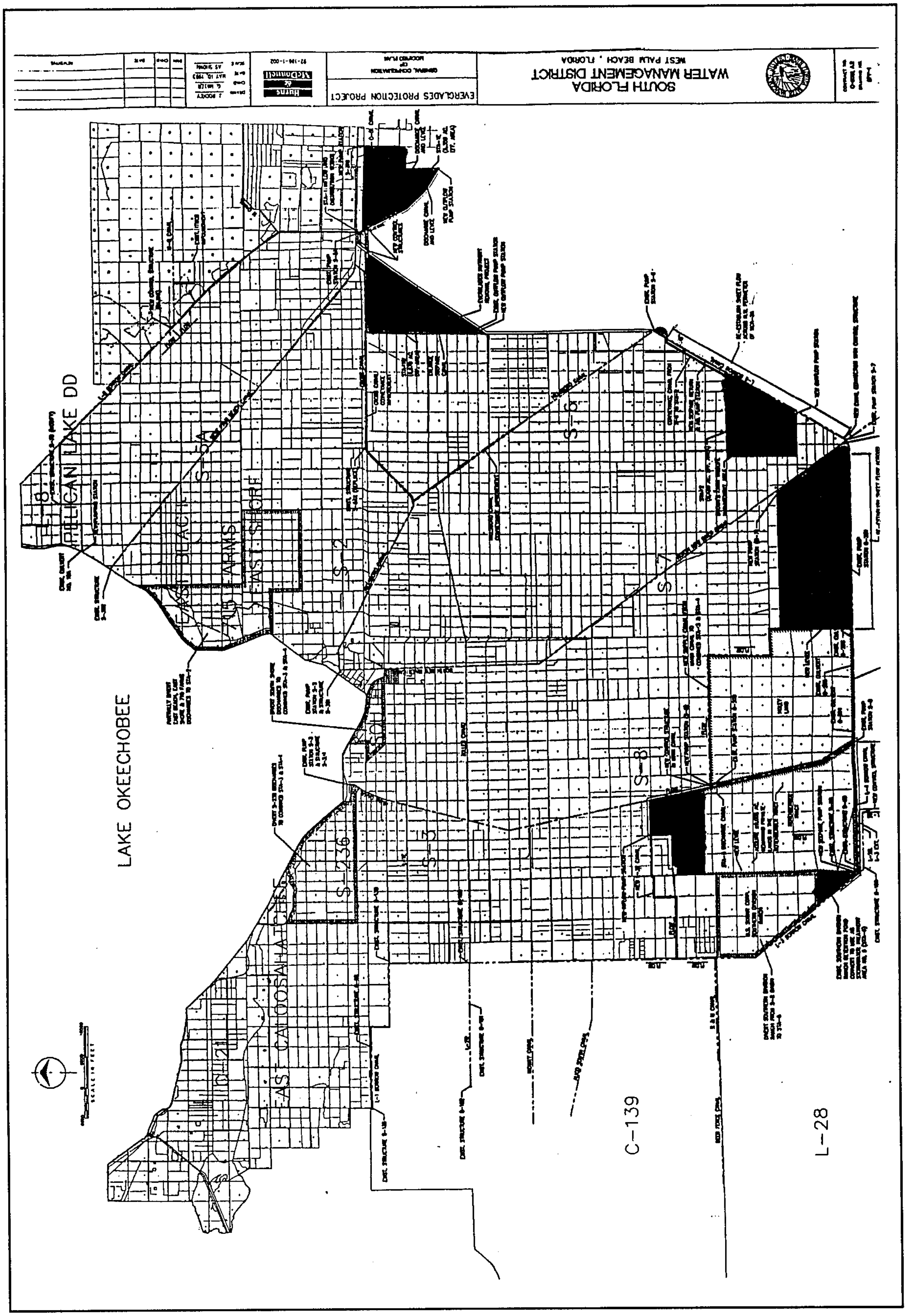


*Figure 3. South Florida Water Management District*

be taken to specify the residence time. The final negotiated calculations for the plan have used the net accretion rate (Kadlec):

$$Accretion\ rates = S' - L$$

where

$L$ = Soil sediment loss because of oxidation and leaching in g/year

$S'$ = Gross accretion as agreed to above

Since the State STAs may never undergo a complete dryout, some scientists feel the observed phosphorus removal rates will never approach the rates found in the original investigations in areas that did experience complete dryout. Also since the sites will not be planted with specific species of plants, phosphorus removal rates may not be totally predictable.

The Corps has no specific authorization or funding to assist in the completion of these items; however, under current operating and maintenance budgets, it has agreed to provide technical review and monitor the project extensively. At this time, the Corps is assisting in the State operated STA Nutrient Removal pilot test, which has been set up to determine the most efficient way of managing the areas for nutrient removal. This pilot test will demonstrate the efficiency of the STAs on a large scale and provide additional information on construction, operation, and maintenance. It will also test the efficiency and manageability of different vegetation types in the STA polishing cells. It will test the possibility of scheduled dryouts in the STAs, test the effects of deeper and shallower hydrologic regimes and loading rates, and test for performance of polishing cells at the end of the system, which have been designed to remove the phosphorus to less than 7 ppb. The Corps is also supporting the field-monitoring plan needed to support the ecological and numerical interpretations of the States "no imbalance to flora and fauna" water quality standard to the Everglades. Through the Settlement Agreement, the Corps is participating in studies to determine what the threshold concentration of nutrients are that may be used as standards to control the possible future degradation of the Everglades areas.

At this time, the Corps continues to monitor the quality of water in the South Florida area in the vicinity of the structures they operate. There is one cooperative MOA in preparation by all agencies concerned to determine how to come up with funds to continue the monitoring of the nutrient removal projects and the nutrient threshold research.

## The Future

The Corps has applied for the Settlement Agreement Operating Permit for the Structures they own and operate. The State of Florida is now developing monitoring and operating controls they wish to issue as conditions of the permit in order to ensure water quality. The Corps is negotiating to ensure any such conditions can be met without adverse impact to the multipurpose function of the C&SF project. The MOA being negotiated requires the Corps to participate in the research, and Corps technical specialists are working with the South Florida Water Management District, the Everglades National Park, the U.S. Fish and Wildlife Service, and members of the National Biological Survey on the research for nutrient criteria. The Corps is negotiating with the above agencies on existing monitoring and the monitoring required for another vital project. This is the modifications to existing water flow to the Everglades National Park to more closely approach the original deliveries prior to the construction of the C&SF project.

The operation of the Nutrient Removal Project will be monitored to ensure that the required removal rates are achieved or future construction plans altered to reflect the actual results.

There are still challenges and litigation from agricultural interests involving the implementation of the Settlement Agreement.

Another mediated settlement agreement between governmental agencies and the agricultural interests has been negotiated but is temporarily on hold and litigation is ongoing.

The Corps is also studying the effects that diversion of water through the STAs will have on the efficiency of water deliveries through the system.

The Corps intends to continue to take an active role within its congressional authorizations and missions to ensure the quality of the water to be delivered to South Florida and ultimately the Everglades National Park.

## Acknowledgments

The author appreciates the support of the U.S. Army Engineer District, Jacksonville, in preparing this paper. The views expressed, however, are those of the author and do not necessarily represent those of the United States or the U.S. Army Corps of Engineers.

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# Evaluation of Environmental Management Processes Associated with Restoration of Hamlet City Lake

*by*
*Philip M. Payonk*[1]

## Introduction

Quality management has become pandemic in our society. Improvements of quality in products and services are national priorities as never before (U.S. Office of Personnel Management (OPM) 1991). Improvement of environmental management service quality associated with U.S. Army Corps of Engineers (Corps) projects involving dredging and dredged material disposal is a desirable professional and organizational goal. Such improvement requires an understanding of the interrelationship of customer requirements and expectations and the scientific process. This paper examines environmental management activities associated with a small dredging project from a quality management perspective. The work performed was believed to be scientifically or technically correct for the situation, but resulted in a less than satisfied customer. The results may provide insight into ways to improve the environmental management services that a Corps District provides to the public.

## Environmental Management as a Process

Corps Districts have responsibility for management of a variety of projects that include dredging and dredged material disposal activities. This management is a process, a set of interrelated work activities that are characterized by a set of specific inputs and value-added tasks that produce a set of specific outputs (AT&T 1989). As shown on Figure 1, a process has inputs provided by suppliers and outputs provided to customers. Project management consists of a collection of subprocesses or nested processes, each of which provides information or value-added tasks to the overall task. Compliance with environmental requirements and criteria is a controlling factor in Corps projects. Therefore, the environmental management process is important in accomplishing institutional project objectives.

## Dredged Material Management Strategy

For Corps projects involving dredging and dredged material disposal, an important subprocess of environmental management is a process for determining environmentally acceptable placement (disposal) alternatives for dredged materials. Francingues et al. (1985) and U.S. Environmental Protection Agency (USEPA)/U.S. Army Corps of Engineers (USACE) (1992) provide a dredged material management strategy. The strategy is a process to identify alternatives for the management of dredged materials consistent with and meeting the substantive and procedural requirements of applicable environmental requirements. The Corps' dredged material management strategy is a technical framework for obtaining information needed to make project management decisions. Thus, the Corps' dredged material management strategy is process nested within the Districts' environmental management and project management processes.

[1] U.S. Army Engineer District, Wilmington; Wilmington, NC.

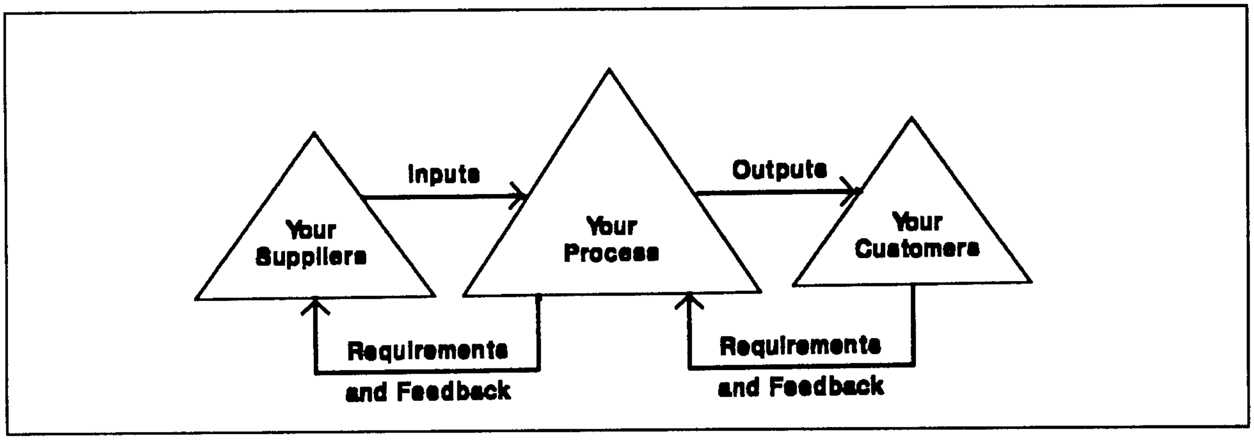


*Figure 1. Management process model (AT&T 1989). This model is applicable to environmental management of dredging and dredged material disposal projects*

## Multiple Customers - Multiple Suppliers

A customer refers to the recipient or beneficiary of the outputs of the process work efforts (AT&T 1989). Suppliers are the individuals or groups who provide inputs to the process. Supplier-customer relationships are reciprocal (Carr and Littman 1990). The supplier provides services to the customer and the customer provides information to the supplier in terms of requirements and expectations. The environmental manager employing the dredged material disposal strategy has multiple customers. The multiple customers include internal and external elements. Internal customers include other District elements whose work on the project comes after or depends on the environmental process. External customers may include the non-Federal, cost-sharing partner, the regulatory community, and the public. The voice of individual customers can vary with their degree of vested interest in the project. The local sponsor supplying funds will expect much more than the sometimes silent general public. Yet to a service supplier, both are important.

## Quality

The goal of all management processes described above is to produce products or services that conform or meet the users' (also known as customers) requirements, expectations, or needs. This goal establishes a basic level of quality. Several factors add to the complexity of this task. As discussed previously, the customer is usually not singular but a multiple cast. Therefore, there may be multiple views of quality because there are multiple needs. Customers also commonly state their needs from their point of view and in their language. There may be perceived needs (what we think we need), real needs, and cultural needs (institutional needs)(Juran 1992). For environmental management in the public sector, conforming to requirements can mean that the product or service conforms to environmental legislation, institutional guidance and policy, budget requirements, and has acceptable public perception. Quality in dredged material management may mean providing reliable, technically defensible, cost-effective information to project engineers and managers and the regulatory community.

## Hamlet City Lake Project

The environmental management activities associated with the Hamlet City Lake Project are examined from a quality management perspective. Improvements to Hamlet City Lake, Hamlet, NC, were authorized by the Water Resources Development Act of 1986, under Section 602, Lakes Program. These improvements were later funded by the Energy and Water Development Appropriation Act of 1988. The authorizing document instructs the

Corps of Engineers to carry out a program for the removal of accumulated silt and debris from the lake. The project was sought by local interest to restore the lake to its previous attractiveness and usefulness as a recreational feature of the City of Hamlet. The lake's aesthetic qualities and usefulness had deteriorated because of the excessive growth of aquatic weeds and plants because of the lake's shallow depths caused by sediment deposits. The authorization provided that the City of Hamlet (the local sponsor) would enter a Local Cooperation Agreement and cost share 25 percent of the total project costs.

The Wilmington District began preliminary designs to remove lake sediments and place those materials within an upland confined disposal site adjacent to the lake. A reconnaissance survey of bottom sediment thickness and physical characteristics conducted in August 1988 revealed that the bottom sediments were mostly organic clays and poorly graded sands with the predominant material being an organic plastic silt. The sediments contained an oily substance that "had a hydrocarbon smell similar to diesel or fuel oil" (USACE 1989). A review of available information revealed a high potential for surface water runoff transporting contaminants from an urban area and an abandoned railroad repair facility. There was "reason to believe" the sediments may be contaminated.

Given the strong evidence of contaminants in the lake sediments, Wilmington District contacted the U.S Army Engineer Waterways Experiment Station (WES) and requested them to apply the Corps Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls (Francingues et al. 1985 and incorporated by reference in the Corps Dredging Regulation 33 CFR Parts 309, 335-339) in developing plans for sediment removal and disposal. The sediment testing program that resulted is described in Table 1.

The testing program results indicated that Hamlet City Lake sediments could be removed and placed in an upland disposal site with management strategies that would minimize impacts to the disposal environment (Tatem et al. 1992; Brannon, Meyers, and Price 1992). Based on the application of the management strategy, the initial plan for hydraulic dredging with discharge and retention of materials in a confined disposal facility adjacent to the lake was replaced with a plan to mechanically dredge and landfarm the dredged material within a confined disposal facility several miles from the lake.

## The Quality Management Analysis

### Four Basic Principles

In quality management, there are four basic principles that organizations have used to improve customer satisfaction by improving the work processes of the organization: management by data, customer focus, continuous improvement, and employee empowerment (OPM 1991). These principles will be the framework to assess Hamlet City Lake Project environmental management and the subset, dredged material management process.

### Management by Data

Decisions or management by data require two components: a system of gathering technically reliable and accurate data to conduct a work process, and a system of gathering information to determine the degree that the services provided are responsive to the customers' needs. The Wilmington District's Hamlet City Lake Restoration Project efforts to manage by data were strong on the first component but needed significant improvement on the second.

Use of the dredged material management strategy provided a framework for obtaining the site-specific technical data necessary for project design and environmental management processes. The strategy considered a broad range of factors, including lake sediment contaminant characteristics, project- and

**Table 1**
**Hamlet City Lake Restoration Project Dredged Material Contaminant Testing and Evaluation of Controls**

| Test | Date | Approximate Cost, $thousands | Reference |
|---|---|---|---|
| Reconnaissance Sampling | 1988 | 5.0 | USACE 1989 |
| *Summary*: Geotechnical sampling to determine physical characteristics of lake sediments. Oily residue and hydrocarbon smell found in some samples. | | | |
| Chemical and Biological Characteristics, Sediment and Effluent | 1989 | 60.0 | Tatem et al. 1992 |
| *Summary*: Sediment samples and effluent prepared with lake sediment and water were chemically (USEPA priority pollutant) and biologically (*Daphnia magna*) tested. Settling tests also performed. Results indicated that sediments were contaminated as compared with nearby upland soils. Contaminants included metals and aromatic and aliphatic hydrocarbons. The elutriate was black with a high amount of suspended particulates. Elutriate testing indicated that effluent discharge would contain suspended particulates that may be toxic to aquatic organisms. Need to filter effluents to meet water quality standards. | | | |
| Sediment Contaminant Mapping | 1990 | 50.0 | Payonk 1990 |
| *Summary*: Lake sediments were systematically sampled (grid) to assess distribution of contaminants. Contaminants of concern were found widely distributed over the area sampled. Small contaminant "hot spots" were not found. Maximum concentrations of specific contaminants were as follows: total recoverable petroleum hydrocarbons - 22,848 mg/kg; lead - 315 mg/kg; cadmium - 9.2 mg/kg; zinc - 444 mg/kg; and mercury - 0.37 mg/kg. | | | |
| Leachate Testing | 1990 | 130.0 | Brannon, Meyers, and Price 1992 |
| *Summary*: Batch and column leach tests and computer simulations used to provide quantitative information on the potential for leachate impacts to groundwater if sediments dredged materials placed in a confined disposal facility (anaerobic and aerobic conditions). Also, the toxicity characteristic leachate procedure (TCLP) was conducted. Results indicate that probable leachate quality may exceed surface and groundwater criteria for specific metals. TCLP criteria not exceeded. | | | |
| Reconditioning and Bioremediation Tests | 1991 | 120.0 | Tatem et al. 1992 |
| *Summary*: This was a series of tests to determine the potential for contaminant mobility when Hamlet Lake sediments are removed from the lake and disposed of in an upland disposal site. Tests included surface water runoff test, organic contaminant bioremediation tests, leachate test for remediated sediments, and plant and animal bioaccumulation tests. The results indicated that disposal by landfarming within a confined disposal facility would be environmentally acceptable. Treatment of disposal area runoff by passing the runoff through a constructed wetland is proposed. | | | |

site-specific characteristics, and potential environmental impacts of dredged material disposal. The strategy is scientifically and experientially based. The data was produced in increments that made the management process a series of incremental decisions. This mandated continuous adjustment of the process. Some decisions regarding major project directions could not be made until the end of the process and that made some customers uneasy participants.

Like many service organizations, the Wilmington District has a structure that divides tasks based on functional responsibilities and technical requirements. The Hamlet City Lake Project at times did not fit neatly into that structure because of the complexities imposed by dealing with contaminated sediments within a small lake. This meant that the process had to change from a local experience base to greater dependence on nationally developed model strategies. The process for delivering outputs, as well as the needs of internal customers, had changed. The need for internal coordination and team effort had increased.

The second management by data component, a system of gathering information to determine the degree that the services provided are responsive to customer need and expectation, was in place only on an informal basis for the Hamlet City Lake Project. Many meetings were held between the Wilmington District

and principal external customers; namely, the City of Hamlet and the regulatory community. However, these were mostly progress tracking meetings instead of systematic evaluative sessions. Customer dissatisfaction grew as the quantity and cost of testing grew.

### Employee Empowerment

The sediment contamination mandated a shift from a group of "individual efforts" to a "team effort." The District also sought out the expertise needed to implement the dredged material management strategy. The Wilmington District used a team approach to address the Hamlet City Lake Project with the best resources available. A multidisciplined District team provided a local knowledge base and a design implementation structure, while WES provided expertise about contaminant testing and controls.

### Continuous Improvement

The use of the dredged material management strategy led to new and innovative alternatives. Each phase of testing produced data that were used to define subsequent testing or design efforts. The testing at first seemed to identify only additional problems; but with data and appropriate expertise, the project was continued until design solutions became available.

### Customer Focus

The basic needs of principal external customers were not always clearly understood. For example, the City of Hamlet wanted a lake that would be a recreational asset to their community. The authorizing document instructed the Corps to remove accumulated silt and debris. The City did not perceive the need for, or understand, the testing of contaminated sediments as a requirement to improve the recreational opportunities at the lake. This led to large differences in opinion between suppliers and customers concerning data requirements and data acquisition costs. The customer perceived that the environmental risks involved in removal and disposal of contaminated sediments were overstated. From their perspective, none of the sediment tests were necessary. This was contradictory with the professional judgment of the Corps and the scientific process used. Accordingly, a dysfunctional supplier-customer relationship developed.

The multiple customer condition also presented difficulties for environmental management of the Hamlet City Lake Project. Noncommittal or confusing feedback was received from multiple regulatory agencies involved with the project (they are also customers). The regulatory agencies wanted to respond to a complete project design and testing data before making a decision. The City often complained that we were doing more than required by the regulatory agencies.

Internal customer feedback was far easier to achieve as compared with the internal-external comparisons. However, understanding of the dredged material management strategy process and support had to be fostered. This facilitated a sense of ownership in the process and established good communication and understanding of needs and a basis of trust. Understanding needs is the first step in making sure process output meets those needs.

## Conclusions

This review provides insight into quality environmental management at Corps of Engineers dredging and dredged material disposal project. The Hamlet City Lake environmental management process with the dredged material management strategy was in accord with the quality management basic principles of management by data, continuous improvement, and employee empowerment. However, customer focus was problematic for the Hamlet City Lake Project. A customer expected enhanced recreational opportunities and aesthetic resources at a lake. The Corps' assigned task was to remove accumulated silt and debris. The customer was talking the language of urban resource development, while the Corps was talking potential environmental impacts

and sediment contaminants. The customer perceived quality as a quick and economical accomplishment of the job and perceived the Corps' evaluation of contaminated sediments as unnecessary. With such differing expectations and perceptions, satisfaction with the work from either the customer's or the supplier's viewpoint was not attainable.

The work process model suggests a remedy for the situation described above, feedback and communication. The supplier-customer relationship is reciprocal, and communication between the two is essential. Understanding of needs and trueing perceptions requires communication and often education. The environmental manager must integrate science and technology into the management process, which often deals with nontechnical conditions.

Quality management methods focus on customer satisfaction. However, the environmental management services that the Corps provides are among governmental services that Deming (1986) indicates are judged on equity as well as efficiency. The obligation is to be responsive to the customer but not compromise resources deemed important by our society. Feedback or communication of that dual requirement to the customer is critical.

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# Dissolved Oxygen in Releases from White River Basin Lakes

*by*
*Gordon Bartelt*[1]

## Introduction

The White River Basin (Figure 1) includes approximately 27,800 square miles in Arkansas and Missouri. The White River Basin trout fishery is founded on coldwater releases from hydropower operations at the U.S. Army Engineer District, Little Rock, lakes: Beaver, Table Rock, Bull Shoals, Norfork, and Greers Ferry. These lakes are managed primarily for flood control and hydroelectric power generation. Other uses such as water supply and recreation are authorized, but have not in the past been given equal priority with flood control and hydropower operations.

As compensation for the loss of warmwater fish habitat, trout hatcheries were constructed at Federal expense at Norfork and Greers Ferry to sustain a put-and-take trout fishery in coldwater reaches that were created downstream from the projects. The fishery has been highly successful since its development in the late forties and is important to the tourism industry for northern Arkansas and southern Missouri.

Power produced at Little Rock District projects is marketed by the Southwestern Power Administration (SWPA), U.S. Department of Energy. The Little Rock District operates power features of the projects in accordance with loading instructions from SWPA.

## Problem Description

### Lake Stratification and Dissolved Oxygen

Dissolved oxygen (DO) is a basic requirement for aquatic organisms and, therefore, a significant concern in water quality management. The DO present in a lake is the result of the balance between oxygen-producing and consuming processes. The atmosphere is the dominant supplier of oxygen. Oxygen is consumed by (a) the decomposition of organic substances from natural sources, municipal and industrial sources, and nonpoint sources such as agricultural runoff, and (b) chemical reactions such as nitrification and oxidation occurring in the water column and in bottom sediments.

As surface waters in lakes warm during the spring and summer, this water becomes less dense and floats on top of the deeper cold dense water. This process is lake "stratification." The upper warm layer is the "epilimnion," and the lower cold layer is the "hypolimnion." There is very little mixing between the layers. During the time the lakes are stratified, the epilimnion receives oxygen from the air. The hypolimnion is where most of the oxygen consumption described above is occurring. It is not receiving any oxygen from the air to replenish that being consumed.

[1] U.S. Army Engineer District, Little Rock; Little Rock, AR.

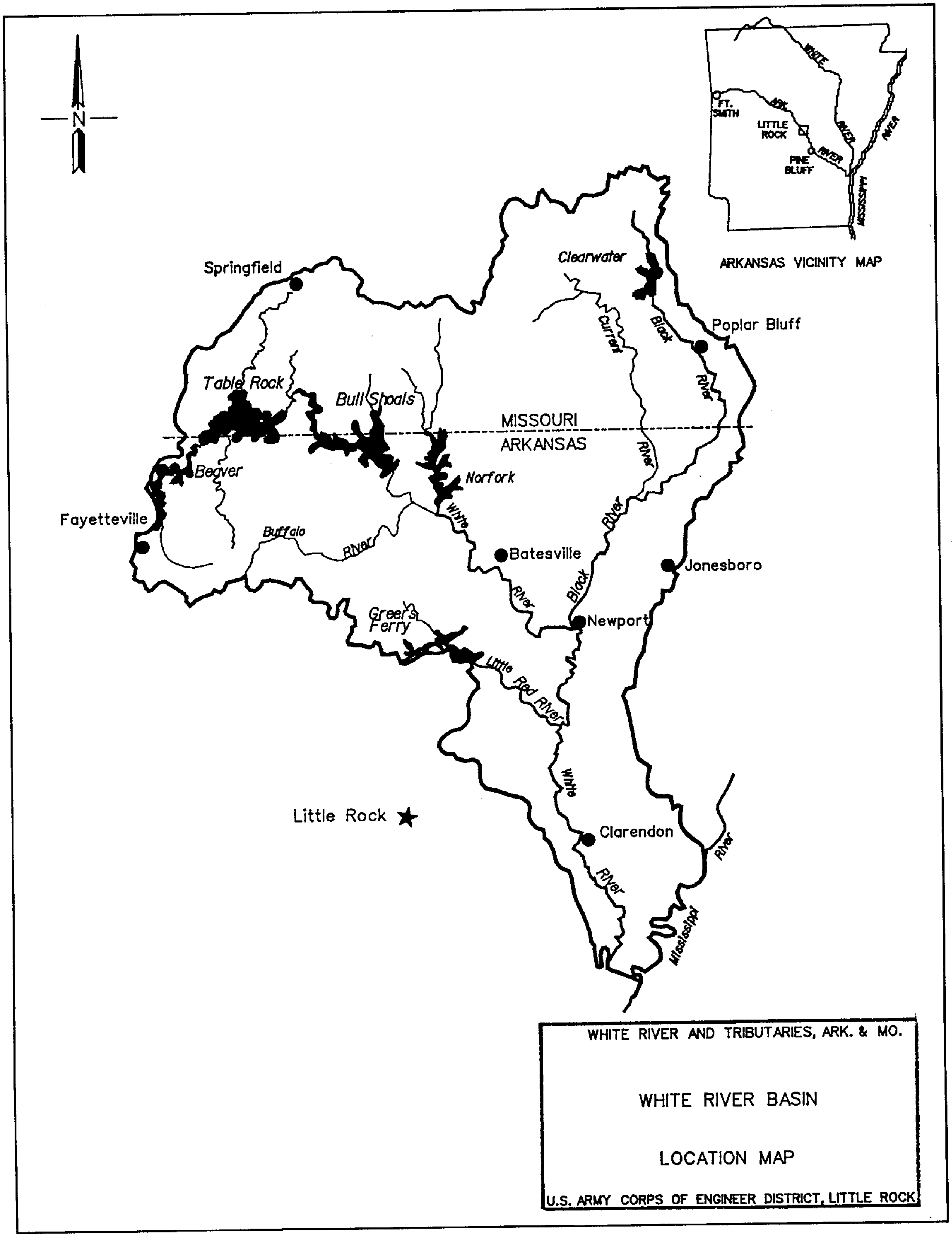


*Figure 1. White River Basin*

Lake stratification typically continues until early December in the White River Basin lakes. At that time, the epilimnion has cooled and become denser so that the entire lake begins to mix.

## Impact of Hydropower

Hydropower generation is a very important and attractive energy source. It is renewable and flexible since it can be stopped and started quickly, making it important in supplying daily peaking power. Hydropower is also one of the cleanest major sources of electricity. However, since the intakes at the Little Rock District hydropower plants in the White River Basin are located so they draw water from the hypolimnion, water low in DO is released. This problem was first encountered in the Little Rock District at Table Rock Lake. Recently, the problem has also become of concern at Bull Shoals and Norfork. The problem is most pronounced immediately downstream of the powerhouse tailrace since DO is replenished because of turbulence as flows move downstream.

## Project Descriptions

Table Rock and Bull Shoals Dams are located on the White River and Norfork Dam on the North Fork River, a tributary to the White River (Figure 1) Releases from the projects are usually made through hydroturbines with low-level intakes except under flood conditions when releases may also be made through gated spillways. The hydropower plants are operated as peaking plants. Table 1 gives pertinent data.

**Table 1**
**Hydropower Plant Operation**

| Project | Depth at Dam ft | Turbines MW | Maximum Turbine Discharge, cfs |
|---|---|---|---|
| Table Rock | 220 | 4-50 | 15,400 |
| Bull Shoals | 190 | 4-40<br>4-45 | 28,800 |
| Nortork | 160 | 2-40 | 7,000 |

## Past Studies and Reports

Several past studies of the low DO problem at Table Rock have been performed. The Little Rock District prepared a reconnaissance report (U.S. Army Engineer District, Little Rock 1985) that attempted to analyze all available solutions to arrive at the "best" one or combination of solutions. The Little Rock District evaluated several alternative solutions, grouped into three categories, (a) water blending alternatives, (b) addition of air, and (c) addition of molecular oxygen.

The use of a blending alternative, i.e., a selective withdrawal structure that could take water from all levels in the lake, was found to be the most feasible. Mathematical and physical model studies of a selective withdrawal structure were completed by the U.S. Army Engineer Waterways Experiment Station (WES)in 1988.[1] Results indicated a multi-level intake structure could not achieve desired water quality. When DO levels were raised to acceptable levels by mixing warmer oxygen-rich surface water, water temperature of the releases was too high. WES then suggested in-lake hypolimnetic oxygen injection. This alternative had been considered in the 1985 reconnaissance report but had been rejected at that time as unproven. Since then the Corps has gained experience designing and operating such a system at Richard B. Russell Reservoir in the Savannah District.

WES did a study of the hypolimnetic oxygen-injection alternative, alone, and in combination with other alternatives such as penstock oxygen injection and turbine venting. They also did field work during the summer and fall of 1989, to provide design and location alternatives, and to help size a hypolimnetic oxygen injection system for Table Rock. The

[1] Memorandum for Record, January 1988, "Selective Withdrawal Study of Table Rock Lake Outlet Structure," Steve Wilhelms and Dottie Hamlin, WES, Vicksburg, MS.

results of this work were reported to the Little Rock District by WES in June, 1990.[1]

## Short-term Interim Measures

While studies toward a long-term solution were being pursued, interim partial solutions were being tested and used to avoid fish kills and still allow power to be generated.

### Block Open Vacuum Breaker Valves

One temporary solution tested was to block vacuum breaker valves in the air vent pipes to the turbines open, and to restrict generation to as low as 20 MW per unit compared with the rated 50 MW. This causes more air to be aspirated, but at a cost of increased cavitation damage to the turbines, reduced turbine efficiency, and loss of capacity and therefore reduced power revenues. This technique is currently being used at Table Rock, Bull Shoals, and Norfork.

### Compressed Air Injection

Air compressors were used to provide air to diffusers in Table Rock lake upstream of the dam, with little success. Compressed air was also injected into a number of locations in the penstock, turbine air vent line, and draft tube. All the compressed air options tested were only partially successful. The large number of compressors required would require a considerable initial investment and consume substantial amounts of power.

### Liquid Oxygen Injection

Another test at Table Rock was injection of molecular oxygen into the penstocks. This proved to be more successful than injection of compressed air. Therefore, a penstock oxygen injection system was built at Table Rock in the early 1980s. This system gives SWPA more flexibility. If they need the power they can increase generation above the restricted levels. However, the injection system is inefficient and expensive to operate. Most of the time, SWPA follows the generation restrictions rather that inject oxygen into the penstocks.

### Interagency Coordination Efforts

In Arkansas, low DO levels became an issue in the fall of 1990 when the Arkansas Department of Pollution Control and Ecology (ADPCE) issued an Emergency Order to the Little Rock District to cease hydropower releases. This order was issued on the basis of violations to the State water quality standards, and because of a reported fish kill downstream of Bull Shoals. As a result of that order, a committee to coordinate State and Federal actions into a plan of operation related to the low DO problem was formed. The White River DO Committee (WRDOC) is composed of representatives from the Little Rock District, SWPA, ADPCE, Arkansas Game and Fish Commission (AG&FC), Arkansas Soil and Water Conservation Commission, Arkansas Department of Parks and Tourism, Missouri Department of Conservation, and Missouri Department of Natural Resources. The initial goal of the WRDOC was to coordinate actions and to foster improved trust and credibility among all the agencies involved. The WRDOC has been very successful in this effort.

The short-term operational plan agreed on by the WRDOC to be followed at Table Rock, Bull Shoals, and Norfork is to restrict generation to discharge rates that will not result in DO of less than 4 mg/L in the turbine releases. This is a temporary measure that prevents trout kills. The operations plan is voluntary and follows procedures that are within the current institutional, legal, contractual, and physical capabilities of each agency involved in the operation of the dams and trout fishery. This procedure has been used at Table Rock for

1 Memorandum for Record, June 1990, "Improving the Dissolved Oxygen in the Releases from Table Rock Dam," Stacy Howington and Ed Meyer, WES, Vicksburg, MS.

many years, except penstock oxygen injection is also available at Table Rock. The consensus of the WRDOC members is that the operational plan has been effective in reducing the potential for fish kills, but it will not produce 6 mg/L and has severely reduced hydropower production. The cost to SWPA (lost energy revenue) and its customers (efficiency losses and additional expense for higher priced replacement energy) in 1992 from generation restrictions at Bull Shoals and Norfork was $1,377,530. In addition, SWPA estimates if 1992 limits were placed on these two projects permanently, total capacity losses would equal $25,400,000 per year. The Little Rock District suspects there is potential for substantial cavitation damage to turbines at Norfork and Bull Shoals from running at very low generation rates. Some damage has been observed at Norfork Unit 1 after using the operational plan during the 1991 and 1992 low DO seasons.

With the help of WES and other WRDOC members, the Little Rock District has run tests on the hydropower plants at Norfork and Bull Shoals, to see if we can increase DO levels by increasing air flow through the turbines. With increased air flow, the units could be run at higher generation rates while still keeping DO levels high. Tests in August 1993 showed we have been successful in improving the DO at Bull Shoals by using improved vent pipes on Units 5-8 and hub deflectors on Units 1-4. At Norfork, because the turbine design is different from those at Bull Shoals, improved vent pipes and hub deflectors did not increase air flow.

The short-term operational procedures are within our existing capability; however, during critical periods of low DO, none of these procedures are expected to produce DO concentrations in releases as high as 6 mg/L. We would like to do better with a long-term, permanent solution.

## Potential Long-term Solutions

### Reaeration Weirs

Downstream weirs alone are not capable of increasing DO levels to 6 mg/L. They can, however, increase levels as much as 3 or 4 mg/L under favorable circumstances. Their biggest drawback is that they reduce available head for hydropower operations unless constructed far enough downstream to minimize backwater. They will also restrict boaters use of a section of the fishery.

### Turbine Venting

DO increases of 1 to 4 mg/L can usually be expected from turbine venting systems. This technique would need to be used in combination with others. Drawbacks include increased maintenance required because of cavitation and a reduction in turbine efficiency of 1 to 3 percent resulting in a loss of power revenue. This technique is already being tested as a short-term solution.

### Autoventing Turbines

These turbines have runners specially designed to provide aeration while at the same time increasing the hydro units efficiency. This is a promising and cost-effective technique for improving DO when original turbine runners need to be replaced at the end of their useful life. The technology is still relatively new. These turbines are unlikely to produce releases with 6 mg/L of DO and will probably need to be used in combination with other techniques. The Tennessee Valley Authority is installing these turbines at their Norris project, and we will be following the prototype performance carefully.

## Hypolimnetic Oxygen Injection

This solution involves injecting liquid oxygen into the hypolimnion of the reservoir. The liquid oxygen is vaporized and transferred through pipes submerged in the reservoir. It is released directly into the hypolimnion in the form of small bubbles through diffusers. A "pool" of oxygenated water is created in the reservoir upstream of the dam. Hydropower releases are drawn from this "pool." This system should be able to meet any release DO target level. The main drawback is the substantial annual cost of purchasing or producing the liquid oxygen.

## Conclusion

A wide variety of techniques are available to improve the DO of water released from hydropower projects. The most effective system for a specific hydropower site will depend upon many factors, including the degree of DO enhancement required, rate of release, and turbine type and operation. Selection of the best system must involve weighing the costs and benefits of each technique with regard to site-specific concerns.

The short-term operational solutions to the low DO problem will continue to be used as an interim plan until a permanent solution is installed. This results in continuing monitoring costs to the Little Rock District, SWPA, and AG&FC; cavitation damage to the turbines; and loss of energy production and potential loss of capacity to SWPA. The cooperative effort of the impacted agencies will be needed to locate willing cost-sharing partners so that permanent fixes can be evaluated and constructed. We remain confident that through the continued, coordinated effort of the parties involved in the WRDOC, solutions agreeable to all can be achieved.

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# Beaver Lake, Arkansas, Water Quality Enhancement Project

*by*
*George Losak*[1]

## Background

### Authorization

The Beaver Lake Water Quality Enhancement Project was authorized by Section 843 of the Water Resources Development Act of 1986 and amended by the Water Resources Development Act of 1988. The authorization specified that a 1-year comprehensive study be undertaken to identify measures to maintain or enhance the water quality of Beaver Lake. Following the study, a project would be undertaken with its effects being monitored.

### Location

Beaver Lake is located in the extreme northwest Arkansas counties of Benton, Carroll, Madison, and Washington. Beaver Lake was constructed by the Corps of Engineers and placed into operation in 1965. The reservoir's purposes are flood control, hydropower, and water supply. The total storage of Beaver Lake is 1,952,000 acre-ft. The drainage area is 1,186 square miles.

Beaver Lake is the water supply source for the cities of Fayetteville, Springdale, and Rogers. These cities are served by the Beaver Water District, which furnished the assurances that allowed water supply to be included as an authorized project purpose. The Beaver Water District has contracted for the 108,000 acre-ft of water supply storage in the reservoir. Also, Carroll-Boone and Madison County Water districts rely on Beaver Lake for their water source. Benton-Washington Water District, which is on the west side of Beaver Lake, has requested a reallocation of storage for municipal and industrial use.

## Study Phase

A study of the problems and concerns of the water quality problems in the Beaver Lake watershed was conducted by the Little Rock District during February 1988 through July 1989.

### Problems and Concerns

Concerns voiced during the study included high counts of fecal coliform bacteria, poor groundwater quality, toxic wastes, high nutrient levels, taste and odor problems, low dissolved oxygen, elevated iron and manganese concentrations, and landfills. Also, urban runoff and septic tank effluent were suggested as other sources of pollution.

During the workshops, U.S. Army Engineer Waterways Experiment Station limnologists provided guidance that nonpoint source pollution is probably the origin of most of Beaver Lake's water quality problems. Previous studies at DeGray Lake served as a basis for their recommendations.

### Study Methodology

The workshops guided the study direction to concentrate on nonpoint pollution, especially soil erosion. A large poultry industry exists in the basin, and land application of confined animal waste is common.

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1 U.S. Army Engineer District, Little Rock; Little Rock, AR.

Remote sensing and geographical information system work by the Tennessee Valley Authority were utilized during the study. These resources served to identify land use, confined animal operations, and potential problem subwatersheds.

The major land use in the Beaver Lake watershed is forest land. Forest land comprises 63 percent of the watershed. The second most common land use is grassland, comprising 32 percent of the watershed. The grassland occurs mostly in the midwatershed area and the floodplains of large streams in the upper watershed.

The U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS) was tasked to determine confined animal populations, estimate the waste produced by these animals, and estimate best land-use management practices (BMPs) needs within the basin.

The confined animal populations in 1988 were found to be 69.5 million chickens, 3.5 million turkeys, 120,000 swine, and 2,400 dairy cattle. These animals produced wastes totaling 425,000 tons, containing 5,800 tons of nitrogen and 2,600 tons of phosphorus.

## Implementation

The Energy and Water Development Appropriation Act for Fiscal Year 1990, Public Law 101-101, directed the Corps of Engineers to implement BMPs and monitor their effects. The costs of this project are mandated to be shared 25 percent non-Federal and 75 percent Federal. The project is being implemented under two separate agreements. The BMPs are being implemented by the USDA, SCS under terms of a memorandum of agreement (MOA). The cost sharing for this feature is being recouped from individual farmers. The water quality monitoring is being implemented through terms of a local cooperation agreement with the State of Arkansas acting through the Arkansas Soil and Water Conservation Commission as the local sponsor.

The cost of the project is as follows:

| | Federal | Non-Federal | Total |
|---|---|---|---|
| BMPs | $4,490 | $1,475 | $5,965 |
| Water Quality Monitoring | 850 | 285 | 1,135 |
| Project Total | $5,340 | $1,760 | $7,100 |

## Best Land-Use Management Practices

The BMPs are being implemented by the SCS under similar rules used by other USDA programs. Farmers in the watershed volunteer to participate in the project. To date, all of the funds scheduled for financial assistance payments to farmers have been obligated to contracts or long-term agreements (LTAs), as SCS refers to them. Many farmers are on a waiting list to participate in this project in the event of LTA cancellation.

The 309 farmer participants (15 percent) are scattered throughout the watershed. The average Federal share of an LTA is $9,700. Practices being implemented include litter-stacking sheds, dead-bird composters, pasture and hayland establishment, pasture and hayland improvement, ponds, and freeze-proof watering tanks.

A farmer must apply for project participation. The SCS inspects the applicant's farm to determine deficiencies in the farmer's management practices. A nutrient management plan is developed for each farm. The nutrient management plan consists of estimating the total nutrients produced from confined animals on the farm, analyzing the nutrient needs of the farmer's pastures, and a waste-disposal plan.

The farmer and SCS personnel discuss the SCS inspection findings. The SCS personnel offer BMP alternatives to the farmer to fit his financial situation and personal preference so that the nonpoint source pollution from his farm is reduced. Also, the farmer is permitted to choose his implementation schedule. The SCS has standardized plans and specifications for the structural BMPs that the farmer must meet to qualify for reimbursement.

The non-Federal share for the BMPs is being contributed by value of work-in-kind. In most cases, the farmer gets three bids for the work specified in the plan and selects the low bidder. The SCS must inspect the completed practice and certify that the practice meets its specifications before payment is made to the farmer. Along with the SCS completion certification, the farmer must furnish receipts for materials and labor.

As of December 30, 1993, there have been 142 LTAs of the total 309 LTAs that have had construction completed. Even though the LTA construction is finished, the LTAs are not complete until the BMPs have been operated and maintained for 2 years.

## Water Quality Monitoring

Water quality monitoring is the other part of this project. The monitoring is being implemented under terms of a project cooperative agreement with the State of Arkansas acting through the Arkansas Soil and Water Conservation Commission. The objective of the monitoring is to perform an annual nutrient accounting of the nitrogen and phosphorus entering Beaver Lake.

The monitoring network consists of 20 sampling sites. Twelve of these sites are on streams. Six sites are the minimum needed to accomplish the nutrient accounting. Six sites were selected to monitor potential problem areas based on land use and confined animal population in the subwatershed area.

Five of the sites are located in the upstream segment of Beaver Lake. In this segment, approximately 85 percent of the drainage area empties into 20 percent of the volume of the lake.

The contractor, Environmental and GIS, Incorporated, was selected through the sealed bid process. The contract was awarded on 29 January 1992. The contractor accomplished the installation of the stream and overland flow gauging stations in 3 months. The first monitoring data were collected in May 1992.

Base flow samples are collected at 6-week intervals, using grab samplers. Four storm events are being sampled annually with the aid of automated samplers. The samplers collect samples throughout the storm event and store them in a large container. Two storms are sampled during litter application time of April through June. One storm is sampled during the summer growing season of July through September. One storm is being sampled after leaf drop, December 15 to March 15.

Parameters being sampled at the lake and stream sites include pH, water temperature, conductivity, dissolved oxygen, orthophosphate, total phosphorus, ammonia, nitrate, total nitrogen, total organic carbon, total suspended solids, Chlorophyll-*a*, Chlorophyll-*b*, Chlorophyll-*c*, turbidity, and algae qualitative evaluation.

The project also includes monitoring three overland flow sites for 3 years. The overland flow sites consist of a 5-acre watershed with a plywood dam with a "v-notch" weir or opening across the drainage way. These sites do not have a defined channel. Four storm events are sampled per year at the same distribution as the stream sampling sites. Overland flow parameters being analyzed are ammonium nitrogen, nitrate nitrogen, total nitrogen, soluble phosphorous, potassium, total suspended solids, fecal coliform bacteria, copper, nickel, and arsenic.

During the first year of monitoring, the stream-monitoring equipment experienced problems caused by man, animal, and nature. Three sites received varying degrees of vandalism ranging from total destruction of one site, a lightning strike at another, and beaver damage to the stage recorder connecting lines at an overland flow site. The contractor estimates that 15 percent of the first year's data had to be statistically reproduced because of these problems.

It is too early to draw any conclusions from the project data. Trend analysis of the water quality data will be performed for years 3 and 4. The contractor's assessment of the first year's water quality data is that the water quality in the Beaver Lake watershed is favorable for fishery production and other uses.

The overland flow data showed high values of nitrogen, phosphorus, and fecal coliform bacteria exceeding the National Primary Drinking Water Standards. The maximum total nitrogen and orthophosphate concentrations were 24.7 mg/L and 17.7 mg/L, respectively, at the north overland flow site on April 14, 1993, 3 days after an application of chicken litter.

The maximum fecal coliform count in a sample was 141,000 colonies per 100 ml at the south overland flow site in the first sample from the May 31, 1993, storm event. This area was under intense grazing by beef cattle before the May 31 storm. This overland flow site drains directly into Beaver Lake.

## Conclusions

More information will be derived from the sampling information as more data are gathered. This information will be used to develop future strategies to reduce nonpoint source pollutants.

# Brine Disposal Lakes of Southwestern Oklahoma and North Central Texas: Potential for Selenium-Related Impacts on Wildlife

*by*
*Stephen Nolen,*[1] *John Veenstra,*[2] *and Carlos Ruiz*[3]

## Introduction

This study was initiated in response to concerns related to potential selenium (Se)-related impacts associated with proposed portions of the U.S. Army Engineer District, Tulsa, Red River Chloride Control Project, Oklahoma and Texas. Objectives of this study were to evaluate the potential for Se accumulation in proposed brine disposal lakes and to estimate resulting impacts on resident or migratory wildlife.

The study consisted of four principal activities: (a) review of Se-related literature; (b) collection of water quality data; (c) predictive water quality modeling; and (d) evaluation of predicted Se concentrations with regard to impacts on wildlife. Descriptions of all methods, assumptions, and input parameter justification are provided in a detailed study report (U.S. Army Corps of Engineers (USACE) 1993). This paper presents a synopsis of major activities, findings, and conclusions of the study.

## Project Description

### General

The Red River Chloride Control Project consists of varied existing and proposed project elements in southwestern Oklahoma and northwestern Texas. The overall objective of the project is to reduce natural chloride pollution in the Red River Basin by controlling low-flow emissions from naturally occurring salt sources (seeps, springs, and salt flats). These sources currently contribute to chloride levels frequently prohibiting feasible use of Red River waters above Lake Texoma. Detailed descriptions of specific Chloride Control project areas are provided in project design documents (USACE 1976a,b; 1982a,b). Locations of all project areas are shown in Figure 1.

While the overall project includes varying chloride control elements, areas of concern to this study are those employing low-flow collection of brine waters from source areas and transport of these waters to brine disposal lakes. Brine disposal lakes are designed solely for total evaporative reduction in brine-water volume and do not include outlet works for discharge from these systems. Hydrology of these lakes would be dominated by gradually increasing pool volumes over an anticipated 100-year project life.

The Red River Chloride Control Project plan includes provisions for three brine disposal lakes: Truscott Brine Lake, Crowell Brine Lake, and Salt Creek Brine Lake (Area VI). Truscott Brine Dam was completed in December 1982 and began receiving brine inputs in May 1987. The remaining two lakes are proposed for construction. Proposed Crowell Brine Lake served as the major area of focus for this study.

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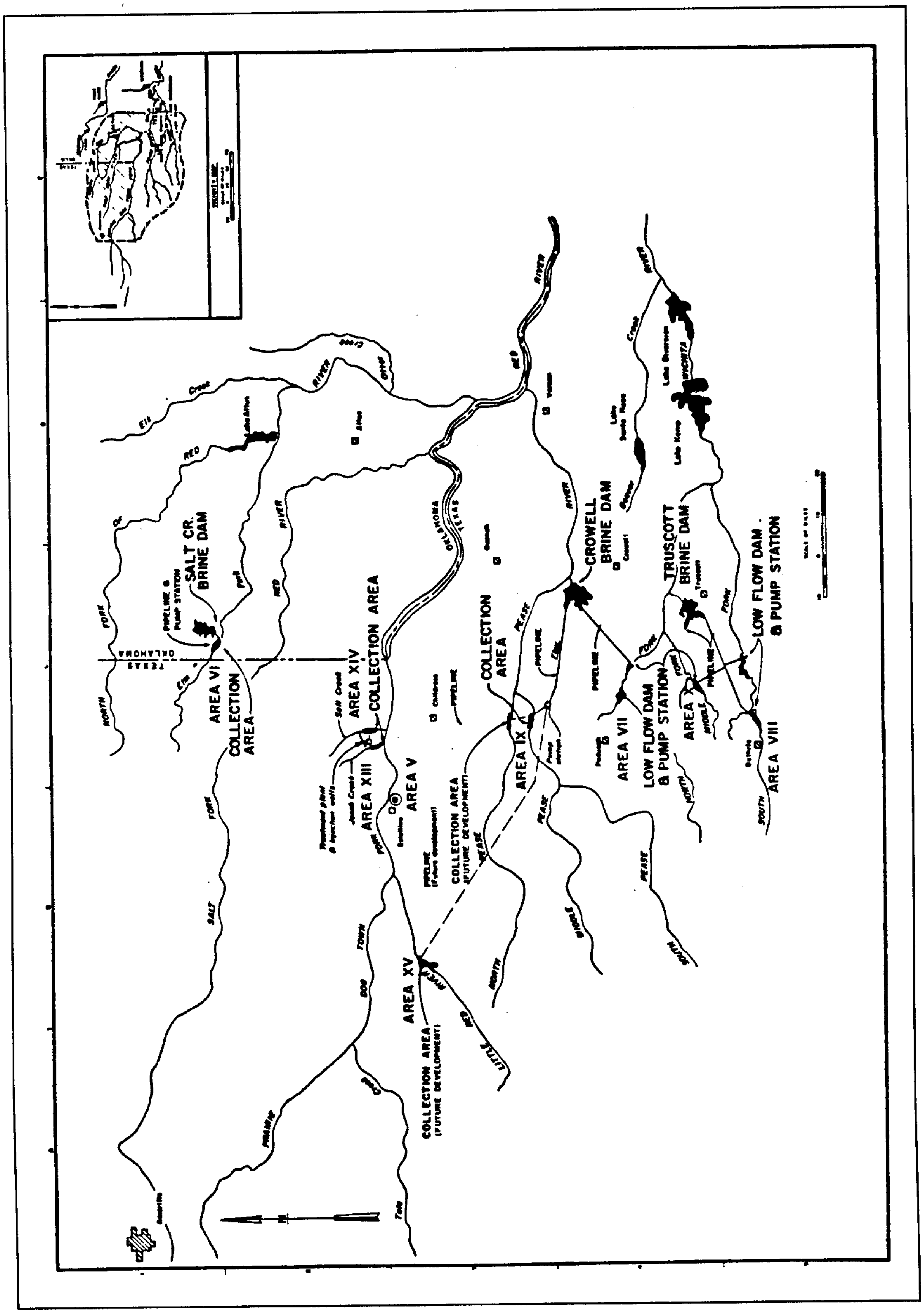


*Figure 1. Red River Chloride Control Project areas (U.S. Army Corps of Engineers)*

## Crowell Brine Lake

Crowell Brine Dam would be located about 5 miles northwest of Crowell, TX, at mile 1.6 on Canal Creek, a south bank tributary to the Pease River. The lake would drain a 46-square mile area of undeveloped and agricultural lands and would serve as the disposal facility for brines collected at source Areas VII and IX (Figure 1). Average pumping rates from source Areas VIII and IX are anticipated to be 8.2 and 5.2 cfs, respectively. At the top of the brine storage pool, Crowell Brine Lake would have a surface area of 3,820 acres, a storage capacity of 110,700 acre-ft, and mean and maximum depths of 29 and 102 ft, respectively. Chloride levels are projected to reach a maximum of 80,000 mg/L over the life of the project.

## Environmental Concerns and Literature Review

An extensive review of Se-related literature is provided in the detailed project report (USACE 1993). Major areas of importance to this study are summarized below.

Selenium is a rather unique element because of a narrow difference between nutritionally essential and toxic concentrations (National Academy of Sciences 1971). Selenium chemistry is highly complex because of the existence of multiple oxidation states, numerous Se-containing organic compounds, and biogeochemical interactions among these forms. Valence states of Se occurring in the natural environment include -2 (selenide), 0 (elemental Se), +4 (selenite), and +6 (selenate). Some organic forms are of particular importance to the Se cycle because of their volatility and resulting ability to mobilize Se from aquatic environments.

Bioconcentration of Se has been documented for a number of aquatic organisms and may be one of the most critical processes affecting expression of Se effects in aquatic ecosystems (Eisler 1985; Lemly and Smith 1987). Algae exhibit a tremendous and varying capacity for Se bioconcentration, with some species possibly capable of regulating intracellular Se concentrations (Foe and Knight 1986). Selenium enters aquatic food chains primarily through direct uptake by primary producers (Pease et al. 1992), and high bioconcentration factors at this level are most likely a critical link in expression of biological effects at higher trophic levels.

Toxic effects of Se may be expressed in two general ways: (a) mortality of juvenile and adult organisms, and (b) reproductive impairment (Lemly and Smith 1987). While a number of studies have documented effects of elevated Se concentrations on varying classes of biota, major research efforts have been devoted to analyzing impacts on aquatic birds—particularly through evaluation of decreased reproductive success (U.S. Fish and Wildlife Service (USFWS) 1992). Impaired avian reproduction and embryonic development may be the first obvious biological indication of Se contamination problems in an aquatic system (Lemly and Smith 1987). Reproductive impairment in aquatic birds is believed to result from the transfer of bioaccumulated Se to avian eggs where toxicologically significant concentrations may be only slightly higher than background levels (Skorupa and Ohlendorf 1991; Skorupa 1992).

A final consideration in evaluating effects of Se on aquatic birds are rates of Se accumulation and elimination. Several studies have concluded that both Se accumulation and elimination are rapid processes in avian species (Eisler 1985; Heinz et al. 1990; USFWS 1992). Results of these studies collectively suggest that as long as migratory birds do not die on wintering areas, leave Se-contaminated areas approximately 2 weeks prior to egg laying, and arrive at breeding grounds physically fit for breeding, reproduction should not be adversely affected by winter exposure to Se (USFWS 1990).

## Levels of Environmental Concern

For purposes of this study, it was necessary to select threshold Se levels that would be expected to result in detrimental impacts on wildlife. As evaporation lakes associated with the project would be constructed solely for disposal of brine waters, fish and wildlife concerns are limited to impacts on semiaquatic organisms tied to these systems via food chain dynamics. Because of a demonstrated sensitivity of aquatic birds to waterborne Se and substantial information regarding impacts on these species, birds became the major focus of the study.

Because of two distinct categories of Se-related impacts on aquatic birds, it was necessary to distinguish between Se criteria for (a) potential reproductive impairment of birds nesting at the project area, and (b) potential detrimental impacts on adult and juvenile birds nesting at sites removed from the project. Since rapid loss of Se from birds has been demonstrated (see above citations), embryotoxicity would not be anticipated for aquatic birds using distant nesting sites. While impacts on these and other organisms undoubtedly vary with chemical Se species, current criteria are generally proposed in terms of total Se. Threshold values for this study were selected accordingly.

In studies relating Se concentrations in water to bioaccumulation of Se in bird eggs, Skorupa and Ohlendorf (1991) proposed 10-µg/L waterborne Se as protective of avian embryotoxicity under most conditions. This concentration was therefore adopted as the critical level impacting avian reproduction at project evaporation lakes.

Based on results of waterfowl feeding studies, the USFWS currently recommends a maximum dietary exposure of 10 ppm for protection of young and adult birds where reproductive impacts are not a concern (USFWS 1990). Use of this dietary value necessitates estimation of waterborne Se levels resulting in 10 ppm in food organisms commonly used by aquatic birds. While a number of complex environmental factors affect the uptake and accumulation of Se in food organisms, empirically derived regression equations developed by Shelton et al. for evaporation ponds in the Tulare Basin of California (unpublished data cited by Skorupa and Ohlendorf 1991) have shown promise in estimating dietary Se on the basis of waterborne Se in egg bioaccumulation studies. Other bioaccumulation regression equations have been proposed by Lillebo et al. (1988) for more freshwater environments, but these systems do not approach ionic strengths anticipated for Crowell Brine Lake.

Skorupa and Ohlendorf (1991) estimated food chain Se concentrations using:

$$\text{Log (BSS)} = 3.25 + 0.49 \text{ Log (WS)}$$

where

BSS = Se levels (ppb, dry weight) in brine shrimp

WS = waterborne Se (ppb, total recoverable)

These authors reported good performance of this equation in estimating the potential for Se accumulation in bird eggs in a number of environments, including those where brine shrimp do not occur. Use of this equation and the recommended 10 ppm dietary criteria yields a total waterborne Se concentration of 34 µg/L. This value was used in this study as the threshold concentration for impacts on adult and juvenile birds in the absence of avian reproduction concerns.

## Study Methodology

### Field Data Collection

Because of a lack of Se data from brine collection areas, the initial phase of the study involved collection of water quality data required as input to predictive modeling exercises. As Se concentrations were anticipated to be highest during low-flow periods, it was the intent of the study to base water quality

predictions on conservatively high Se loading estimates derived from data collected primarily during periods of low-stream discharge. Data were collected approximately biweekly from the end of June to early November 1992, when streamflows at source areas were at a minimum.

Field activities at Crowell Lake source areas (Areas VII and IX) included collection of water samples and measurements of streamflow and field water quality parameters. Water samples were transported to the Corps of Engineers Southwestern Division Laboratory, Dallas, TX, for analysis of total and dissolved Se (EPA Method 7740), total suspended solids, and major anions and cations. Quality assurance/quality control (QA/QC) measures included collection of duplicate samples at an approximate 10-percent frequency, as well as laboratory method blank, reagent spike, matrix spike, and duplicate analyses.

## Water Quality Modeling

Water quality modeling was employed as a means of obtaining reasonable estimates of temporal changes in Se concentrations in water and sediments of proposed Crowell Brine Lake over the life of the project. Modeling output should be viewed as a reasonable screening-level approximation based on currently available scientific information. In an effort to partially mitigate inherent uncertainties associated with Se predictions, reasonably conservative assumptions, estimations, and input data were applied throughout this study where possible.

Preliminary "worst case scenario" estimates of waterborne Se concentrations in Crowell Brine Lake were derived by initially evaluating Se as a totally conservative substance. This approach ignored the influence of factors resulting in reduced water column Se concentrations (i.e., sorption, settling, volatilization, and sediment burial) and was based on simple dilution of Se mass loads by lake water column volumes. While this approach most likely results in gross overestimation of water column Se concentrations, results of this analysis provided absolute worst case estimates and were useful in evaluating the relative significance of factors controlling Se distribution in modeling simulations.

Following development of initial conservative substance estimates, "best estimate" predictions of Se concentrations were obtained by predictive modeling. Upon evaluation of a variety of water quality models, the Simplified Lake and Stream Analysis (SLSA) model developed for the Chemical Manufacturers Association Aquatic Research Task Group (Hydroqual, Inc. 1981, 1982) was deemed most appropriate for use in this study. The model is a relatively simple yet powerful screening tool incorporating mass balance calculations in evaluating effects of point source chemical inputs on lakes or streams receiving waters. A complete discussion of the development and application of SLSA is presented in Hydroqual, Inc. (1981, 1982). Theoretical and site-specific applications can be found in Di Toro et al. (1981) and Di Toro and Paquin (1983).

Water quality modeling for Chloride Control brine disposal lakes was conducted on the basis of total waterborne and sediment Se. Attempts at modeling distribution of distinct chemical Se forms using output from chemical speciation models (i.e., the U.S. Environmental Protection Agency's MINTEQ model) were not conducted. While chemical speciation undoubtedly affects distribution of Se in aquatic environments and availability for biological uptake, published levels of concern with respect to wildlife species have generally been developed on the basis of total Se. The need to directly compare simulation results and levels of concern, combined with the increased complexity of speciation modeling, resulted in predicted concentrations for total Se only.

SLSA input parameters for Crowell Brine Lake Se simulations are presented in Table 1. Many input parameters are based on anticipated "average" conditions over the life of the project. Uncertainty associated with input parameter values not based on actual field or

**Table 1**
**SLSA Model Input Parameters, Crowell Brine Lake Selenium Simulations**

| Parameter | Units | Value | Source/Justification |
|---|---|---|---|
| Volumetric Flow Rate | $m^3\ sec^{-1}$ | 0.001 | Maximizes residence time |
| Water Volume | $m^3$ | 1.39E07-1.37E08 | Varies with pool level |
| Contaminant Loading | $kg\ day^{-1}$ | 0.211 | Source area field data |
| Water Column Depth | m | 4.8-8.8 | Varies with pool level |
| Sediment Layer Depth | m | 0.08 | Rudd et al. 1980; Oremland et al. 1989, 1990 |
| Water Column Suspended Solids | mg/L | 25 | Truscott Lake field data |
| Sediment Suspended Solids | mg/L | 1E06 | Truscott Lake field data |
| Diffusive Exchange Coefficient | $cm\ day^{-1}$ | 50 | Estimated |
| Resuspension Velocity | $mm\ year^{-1}$ | 0 | Minimal for deep lake |
| Sediment Settling Velocity | $mm\ year^{-1}$ | 4.7-6.2 | Varies with pool surface area. Calculated from sedimentation data (USACE 1982b) |
| Water Column Partition Coefficient | L/kg | 100 | Estimated |
| Sediment Partition Coefficient | L/kg | 20 | Estimated from Bar-Yosef and Meek 1987 and Singh et al. 1981 isotherm data |
| Oxidation Rate[1] | $day^{-1}$ | 0 | Not applicable |
| Biolysis Rate[1] | $day^{-1}$ | 0 | Not applicable |
| Photolysis Rate[1] | $day^{-1}$ | 0 | Not applicable |
| Hydrolysis Rate[1] | $day^{-1}$ | 0 | Not applicable |
| Volatility Rate (water) | $day^{-1}$ | 2E-06 | Estimated |
| Volatility Rate (sediment) | $day^{-1}$ | 2E-06 | Estimated |

[1] Water and sediment.

literature data resulted in selection of conservative estimates where possible. While not presented here, complete justification for all input data and assumptions is presented in the detailed study report (USACE 1993).

SLSA Se simulations were conducted for separate 5-year intervals over a total time span of 125 years. Discrete simulations were conducted to mitigate the influence of significantly increasing pool volumes and surface areas during the initial 20 to 30 years of proposed project life. Input parameters dependent upon pool morphometry (water volume, sedimentation rates, and water depth) were varied to match anticipated conditions for each simulation period.

# Results

## Field Data

Total Se concentrations ranged from 5.4 to 9 µg/L at Area VII, with a mean concentration of 7.7 µg/L. Mean total Se at Area IX was 3.8 µg/L, with a concentration range of <1 to 6.9 µg/L. Waters at both areas were well oxygenated with slightly alkaline pH values recorded on all sampling trips.

## Modeling Results

Predicted total Se concentrations for Crowell Lake are presented in Figure 2. When evaluated as a totally conservative substance,

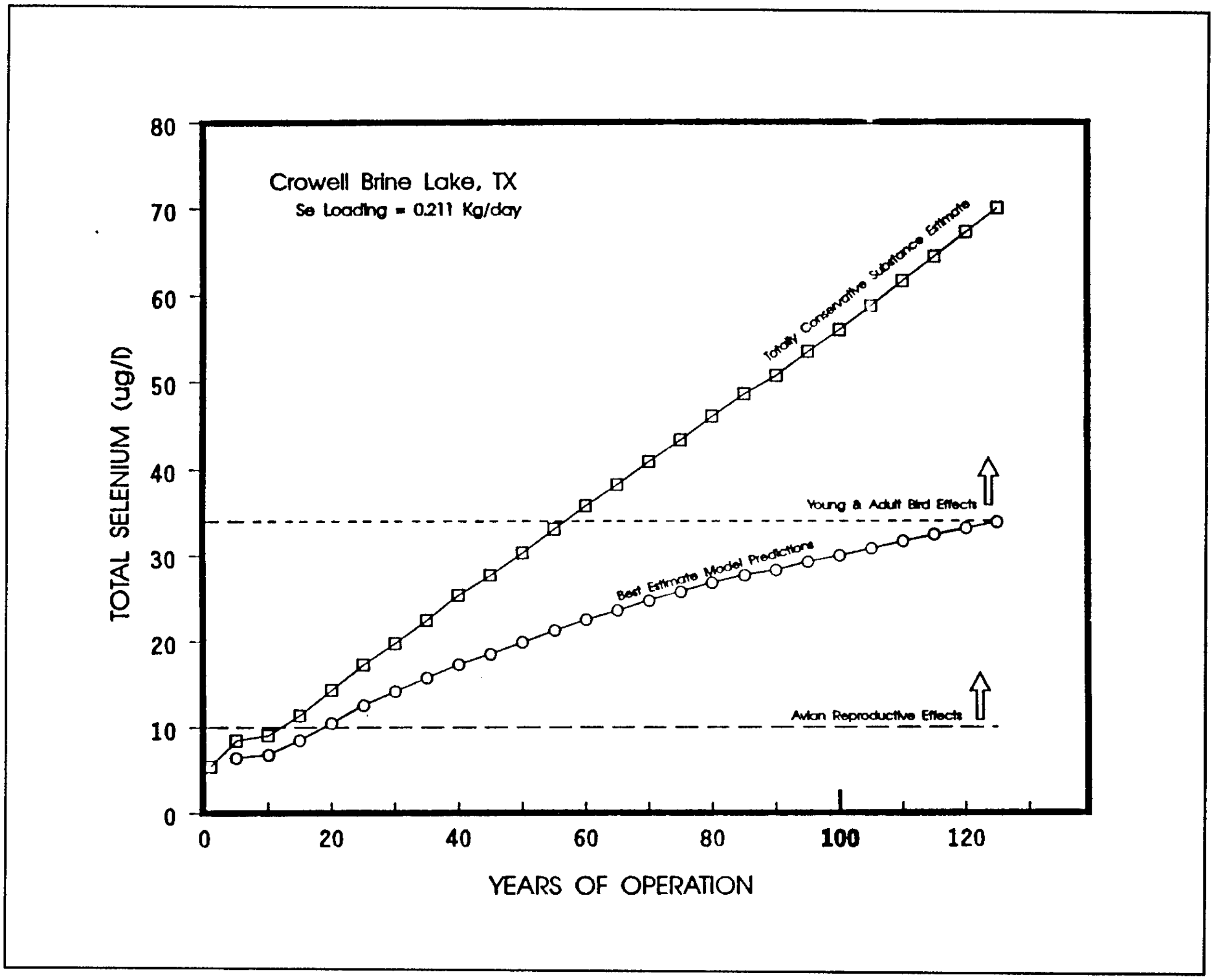


*Figure 2. Predicted total selenium concentrations, Crowell Brine Lake, Texas*

estimated Se concentrations exceed the avian reproductive impacts threshold (10 µg/L) within approximately 10 to 15 years of operational project life. For the same scenario, waterborne Se concentrations would be expected to exceed the young and adult bird effects threshold (34 µg/L) approximately 55 to 60 years after impoundment. Based on this totally conservative substance approach, the 100-year (project life) Se concentration in Crowell Brine Lake would be expected to be approximately 56 µg/L.

Best estimate total Se concentrations based on SLSA model projections are likewise presented in Figure 2. As previously noted, these predictions account for the anticipated influence of sedimentation, sediment sorption and burial, and volatilization in reducing waterborne Se concentrations over the life of the project. Based on all available information and study methodology, these predictions are believed to be both reasonable and somewhat conservative in nature.

According to model projections, total Se concentrations in Crowell Brine Lake would reach levels considered deleterious to successful avian reproduction within approximately 20 years of project operation (Figure 2). As the 100-year predicted concentration is approximately 30 µg/L, deleterious impacts on young and adult birds would not be expected during the anticipated project life. According to further projection, total Se concentrations in excess of 34 mg/L (young and adult bird

threshold) would be anticipated approximately 125 years after impoundment with development of a steady-state total Se concentration of approximately 46 µg/L after 350 years of project operation.

Predicted temporal changes in Selenium levels in Crowell Lake sediments are presented in Figure 3. According to model projections, sediment Se concentrations in the impoundment would be approximately 0.629 mg/kg (dry weight) at the end of the 100-year project life. As these predictions assume no initial Se in preimpoundment lake bed soils, addition of estimated "background" levels of approximately 0.4 mg/kg (based on Truscott Lake sediment analyses) would yield predicted Se concentrations approaching 1 mg/kg 100 years after impoundment. In either case, predicted Se sediment concentrations in Crowell Lake are considerably lower than the 4-mg/kg concern threshold level proposed by Lemly and Smith (1987).

## Conclusions

Based on results of this study, it appears that the most significant anticipated Se-related impacts on wildlife associated with Red River Chloride Control brine disposal lakes would be impaired reproduction of semiaquatic birds nesting in project areas. When applied to current design criteria, water quality modeling estimates indicate that total waterborne Se

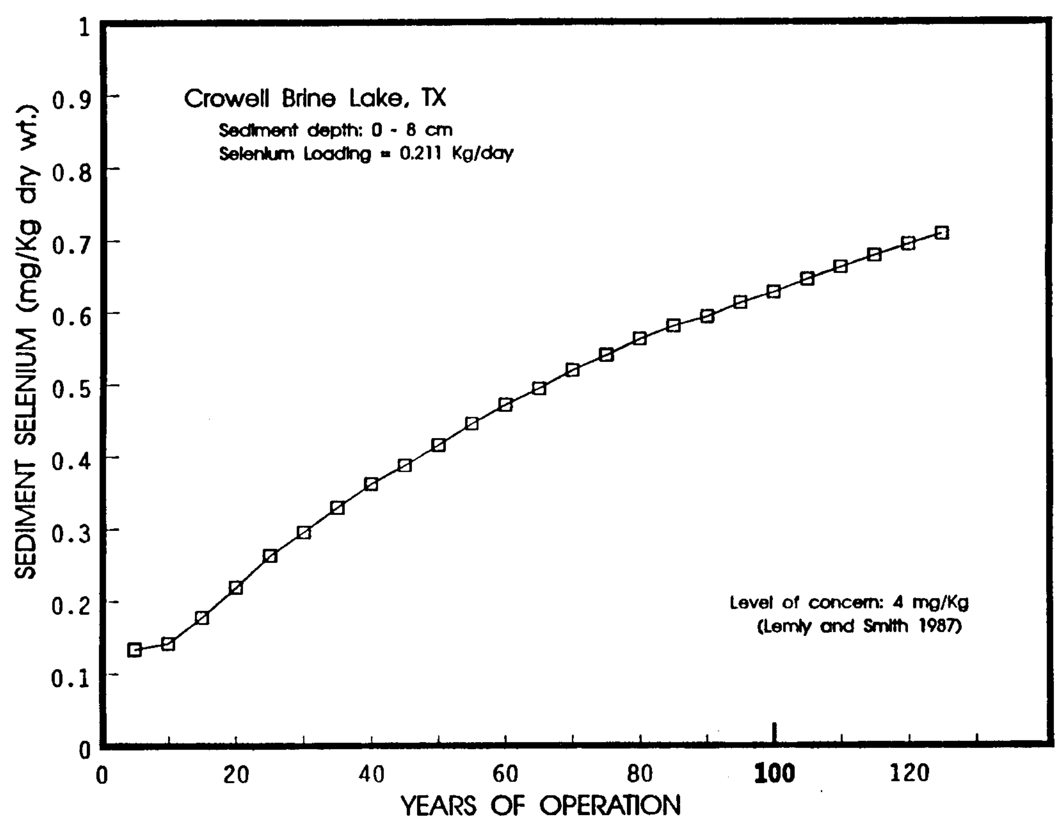


*Figure 3. Predicted sediment selenium concentrations, Crowell Brine Lake, Texas*

concentrations considered deleterious to successful avian reproduction would be realized in proposed Crowell Brine Lake after approximately 20 years of project operation. Reproductive impacts would be most significant to sedentary species closely tied to brine disposal lakes via food chain dynamics.

Water quality simulations, combined with information from the scientific literature, do not indicate anticipated Se-related impacts on young and adult birds temporarily residing at Crowell Brine Lake. Predicted total Se concentrations over the anticipated 100-year project life are below estimated thresholds for impacts on young and adult birds in the absence of reproductive concerns. Because of the documented ability of birds to rapidly lose Se upon leaving contaminated areas, embryotoxicity for birds overwintering at Crowell Brine Lake but breeding at remote sites is not anticipated.

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# Evaluation of Impact of Pesticide Runoff on a Delta Watershed Using HSPF

*by*
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## Introduction

The Upper Yazoo Project (UYP) area is characterized by a hill region in the east and a flat delta region of extensive agriculture in the west. Concern for the potential environmental impacts of the U.S. Army Engineer District, Vicksburg, flood control measures in the UYP area have been expressed by State and Federal agencies. To address these concerns, the District initiated several studies to restudy the water quality in the area. One of those studies was the application of the Hydrologic Simulation Program - FORTRAN (HSPF) on a Mississippi agricultural watershed, Bear Creek, to evaluate the effects on water quality. The model application combined detail simulation of agricultural runoff, sediment, and water quality, such as nutrients and pesticides, with channel simulation of flows and instream transport and transformation.

### Watershed Description

The Bear Creek watershed is located in west-central Mississippi (Figure 1). The total area of the watershed is 84,280 acres with the greatest area located in Leflore County (49,610 acres). The remainder is located in Humphreys (19,110 acres) and Sunflower (15,560 acres) counties. The watershed is flat and low with elevations varying from 90 to 130 ft. It is bordered on the east by the Roebuck Lake and Yazoo River watersheds, and the Little Sunflower River drainage basin is on the west side. Bear Creek discharges into the Yazoo River approximately 5 river miles north of Belzoni, MS (Pennington et al. 1991).

Bear Creek is actually a group of small creeks that connect a series of lakes beginning with Blue Lake in the north and ending with Wasp Lake in the south. The total length of Bear Creek is 50.74 miles. Three distinct topographical areas exist along the creek: the upper portion is shallow, slow flowing, and at times stagnant; the central part is more hilly; and the lower creek contains a series of lakes and is relatively flat. Wasp Lake discharge is regulated by a control structure built to prevent backwater flooding by the Yazoo River. Before construction of this structure, the lower lakes of the Bear Creek were periodically flooded by backwaters from the Yazoo River (U.S. Department of Agriculture (USDA) 1981).

Soils in the watershed are primarily silt and clay (U.S. Army Engineer District, Vicksburg, 1980). Most of the watershed is covered with Dubbs, Dundee, Alligator, and Forestdale soil series. The watershed is predominantly rural. Most of the land is used for agriculture, with about 64 percent in cotton and soybeans, 13 percent in fallow and wheat, and 23 percent in other uses, primarily forest.

### Study Objectives

The objectives of the study were to assess the pesticide and nutrient nonpoint source (NPS) pollution contribution from a typical

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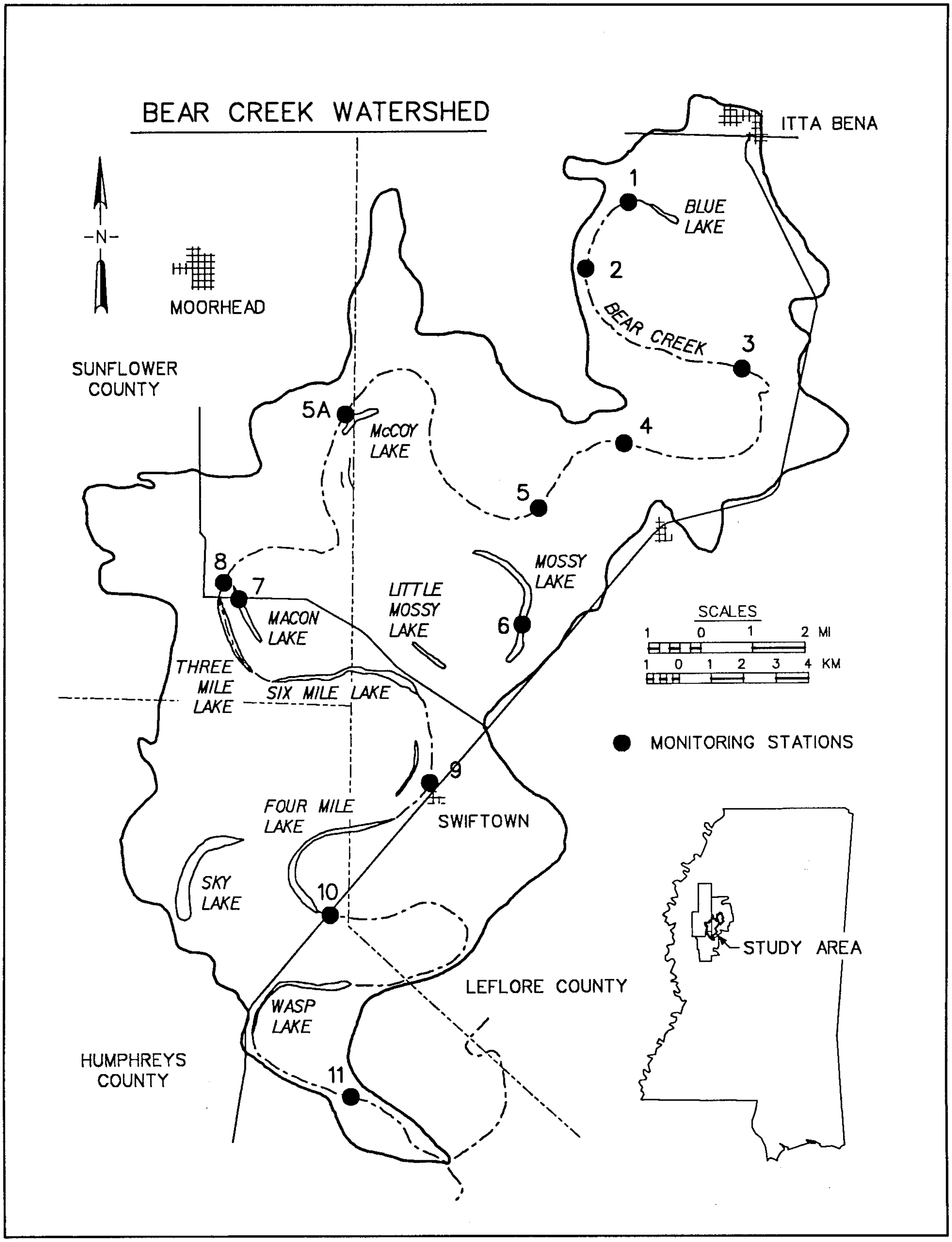


*Figure 1. Bear Creek watershed*

UYP watershed and to evaluate the impact of agricultural runoff and the effect of land-use changes on the Bear Creek watershed using the HSPF model.

## Modeling Approach

The application of HSPF (Johanson et al. 1984) on a watershed is extremely data intensive; there are requirements for meteorological conditions, topography, soil characteristics, land use, streamflow, and agricultural practices. The data were collected from different Government agencies, field investigations, reports of the study area, and personal contacts.

The first step of watershed modeling using HSPF is the division of the watershed into land segments, each with relatively uniform meteorologic, soils, and land-use characteristics. Similarly, the channel system is segmented into reaches, with each reach demonstrating uniform hydraulic properties.

Developing HSPF meteorological time series data is critical for both hydrologic and water quality simulation. The Stoneville, MS, weather station was selected for the weather time series since it was the only station, among four stations near the Bear Creek watershed, whose records contained hourly precipitation data. In addition, daily minimum and maximum temperatures, evaporation, wind movement, and soil temperature were recorded at the Stoneville, MS, station.

The watershed was divided into three segments. The next step was to subdivide each segment into pervious land segments (PLS). The final subdivision was based on land use, soil type, and topography. The land use and soil classification subdivision was done by U.S. Army Engineer District, Vicksburg, personnel. A geographical information system (GIS) was used to compile the contour maps for the watershed from U.S. Geological Survey (USGS) 1:62500 scale maps. Satellite imagery from May 1978, December 1987, May 1988, and March 1989 was used to identify land use within the watershed. Land use was classified into three major categories; agriculture, forest, and water. The agriculture category was further divided into three land uses: cotton and corn; soybeans and rice; and fallow, grass, and wheat. The forest class was defined as bottomland hardwood and cypress-tupelo. The water class consisted of rivers, lakes, and catfish ponds. Each of the three segments (subwatershed) was divided into 5 PLS. There are a total of 15 PLS, 5 per segment, within the entire watershed.

Digitized soil survey maps from Leflore, Humphreys, and Sunflower counties were incorporated into another GIS database. There are 11 soil associations in the watershed. The soil associations are the combinations of two or more soil series. A GIS was used to classify the soil associations in the watershed. Topography, soil class, and land-use GIS databases were then used to determine the boundaries between segments and the contributing areas of the individual reaches.

The entire channel was divided into 29 reaches based on data availability and hydraulic representation of the channel. For model calibration and verification purposes, the reaches were delineated such that stations where data have been collected correspond to reach boundaries. Of the 29 reaches, 11 had the recorded water quality and stages. As a result of segmentation, all land contributing runoff to reaches 1-7 was contained in segment group I; all land contributing runoff to reaches 8-15 was in segment group II, and runoff to reaches 16-29 was wholly contributed by segment group III.

Water quality data, such as pesticides and nutrients, were available for HSPF calibration/verification. Water quality data for 11 stations in Bear Creek were collected by the USDA for the Vicksburg District (USDA 1981; Cooper et al. 1987; Dendy 1981); the data included general water quality parameters, suspended sediments, nutrients, and pesticides. The same 11 stations in the Bear Creek Watershed were resampled four times, corresponding to applications of agricultural chemicals, in 1990 (Pennington et al. 1991).

## Calibration Results

HSPF hydrologic and soil loss components were calibrated against data collected for 3 years in two small subwatersheds in Bear Creek (Dendy 1981). Calibration was done on 1979 data and verification on 1977 to 1980 data. Long-term hydrologic simulations were then performed from 1976 to 1990.

### Hydrologic Simulation

Hydrologic calibration was performed initially for 1979 data to obtain a general water balance. Initial estimates of several parameters were selected from soil moisture conditions, agricultural management practices, and previous applications of HSPF in the Yazoo Basin (Donigian, Meier, and Jowise 1986). Monthly simulated results of 1979 on cotton fields at Station 2 are shown in Figure 2. In general, the predicted runoff provided a fairly good agreement with the measured one as shown in Figure 2. A discrepancy in November was probably due to vegetative cover change, while in September the measured runoff was reported to be an estimated value (Dendy 1981). The simulated annual runoff was 42 percent of total rainfall, as compared with the measured 43 percent; only 1-percent difference in annual runoff was found for the hydrologic calibration of using HSPF.

Hydrologic responses on Bear Creek (i.e., Delta region) were characterized into three components: surface runoff, interflow, and groundwater. Surface runoff was predominant during storm events, and interflow was mainly affected by agricultural management practice. The simulated runoff in this case (calibration and verification) was the sum of the surface runoff and interflow. Parameters of infiltration rate and soil moisture in the upper and lower zones were found to be the most sensitive to model calibration.

Verification was accomplished for 5 years of simulation (1976 - 1980). A summary of

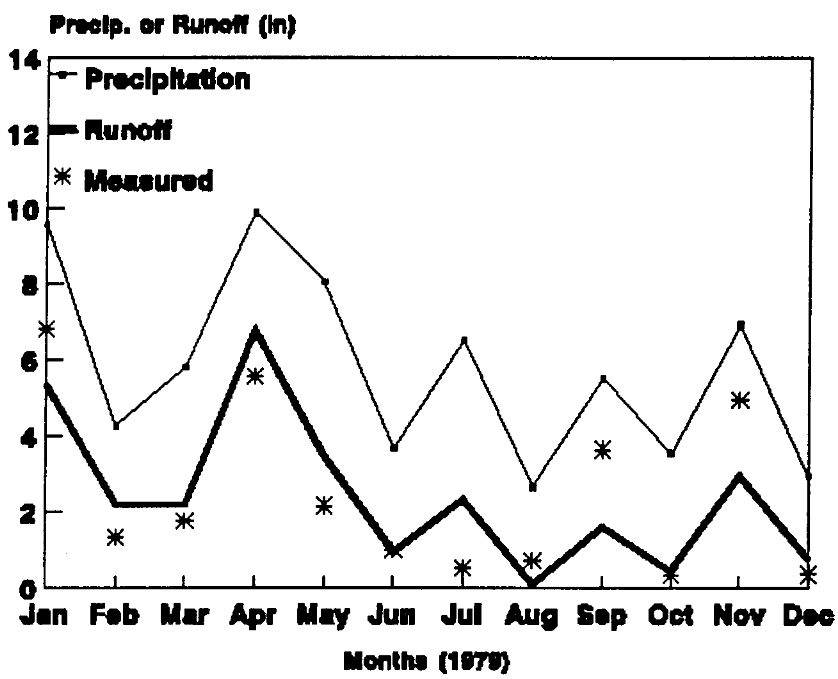


*Figure 2. Bear Creek runoff simulation from cotton fields for 1979*

simulated and observed runoff volume is presented in Table 1, and the results in a long-term simulation are shown in Figure 3. Simulated values were reasonably close to measured data.

**Table 1**
**Summary of Simulated and Measured Runoff Using HSPF**

| Year | Runoff, in. | |
|---|---|---|
| | Simulated | Measured |
| Calibration | | |
| 1979 | 28.9 | 29.3 |
| Verification | | |
| 1976 | 10.7 | no data |
| 1977 | 10.4 | 12.1[a] |
| 1978 | 17.1 | 14.3 |
| 1980 | 15.1 | no data |

[a] Nine-month data only; others months were estimated.

## Sediment Simulation

Sediment yields from land surface were simulated using the calibrated hydrologic conditions. The 1979 calibrated sediment yield (soil loss) for a cotton field near Bear Creek Station 2 is shown in Figure 4. The 1979 calibration shows good agreement between simulated and measured sediment yield. There were distinct seasonal variations in soil loss from the cotton field. Vegetative cover appears to be the predominant factor causing these variations. Monthly sediment yield ranged from 1.95 tons/ha in April when there was essentially no vegetative cover to 0.2 tons/acre in October when cover was good. Predicted annual sediment washoff was 6.0 tons/acre, while the observed was 4.8 tons/acre.

A 5-year verification simulation (1976-1980) is shown in Figure 5. Long-term trends were captured in the verification run, and simulated yields were reasonably close to measured ones. Major discrepancies occurred in the latter part of 1977, where both runoff and sediment washoff were underpredicted. Some of the difference could be attributed to experimental overestimation as stated in Dendy (1981); some difference could be attributed to crop cover.

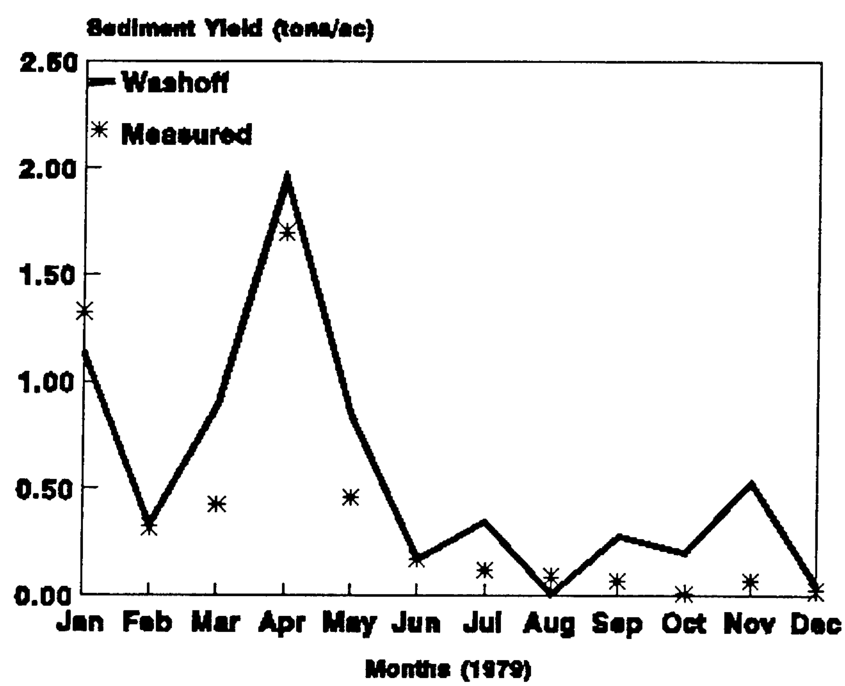


*Figure 3. Bear Creek precipitation and runoff simulation from 1976-1980*

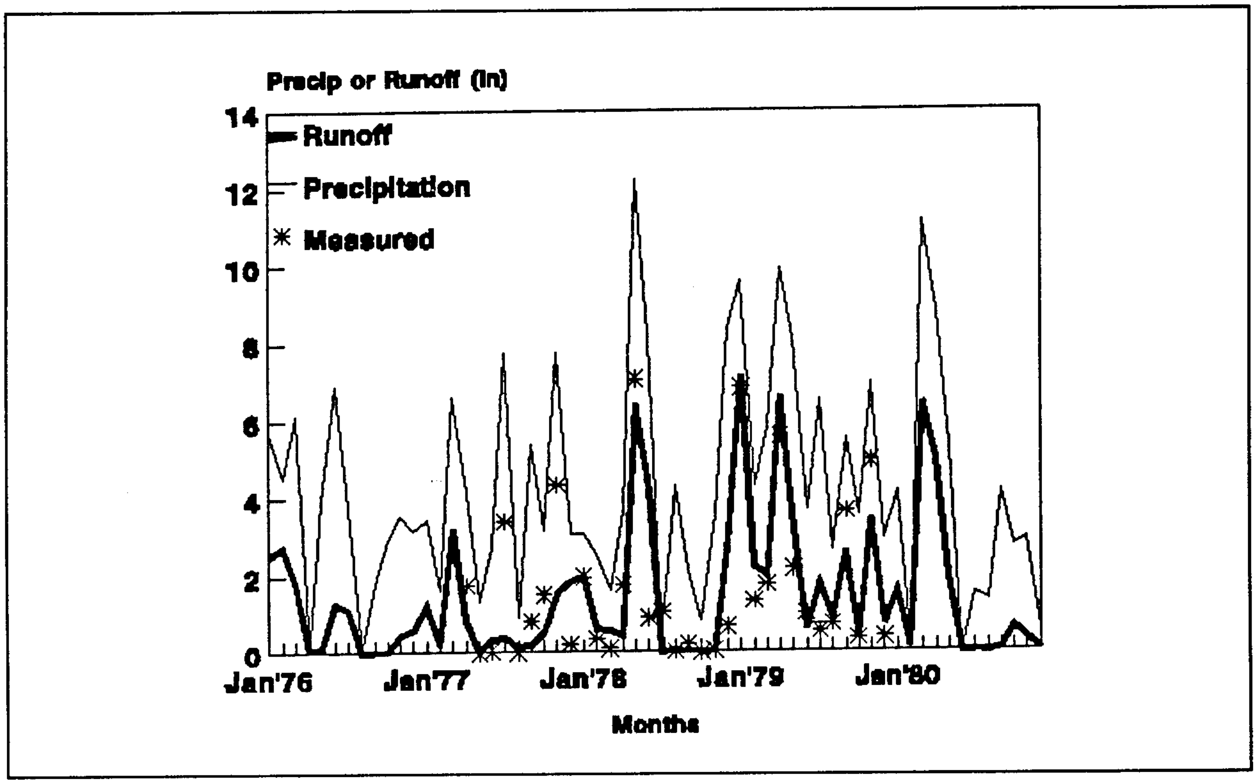


*Figure 4. Soil loss simulation for Bear Creek cotton fields for 1979*

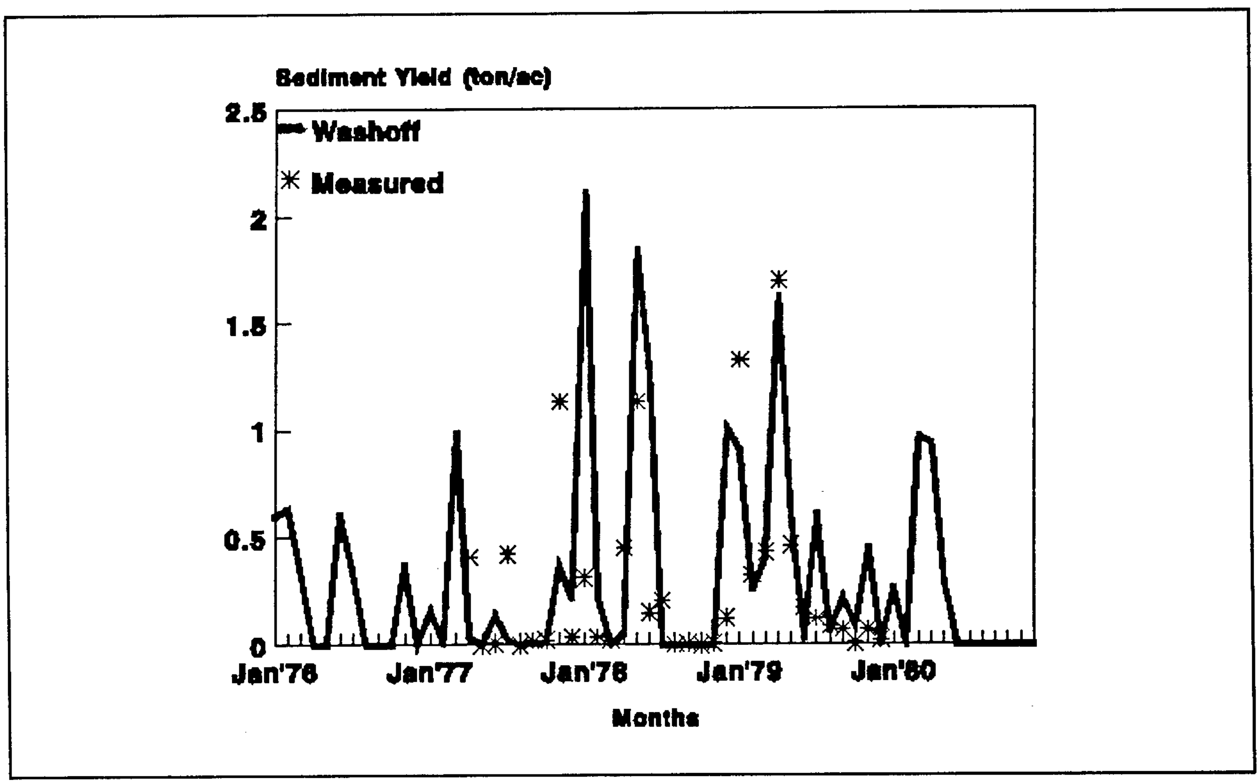


*Figure 5. Soil loss simulation for Bear Creek cotton fields from 1976-1980*

In-channel sediment transport was calibrated using the sediment washoff as the channel load. The instream results indicated that most of the sediment entering the stream was fine material. About 50 percent of the sediment delivered from the cotton fields of the upper watershed settled before reaching the main channel, which was consistent with Dendy (1981) findings.

## Water Quality

Calibration and long-term water quality simulations for nutrients and pesticides were performed after the satisfactory calibration of both runoff and sediment washoff. Calibration/ verification was done against data collected from 1976 to 1979 (Cooper et al. 1987) and 1990 (Pennington et al. 1991). The model was calibrated against 1979 data and verified against 1976-1979 data. Simulations for ammonia and nitrate from 1977 to 1979 for Station 5A are shown in Figures 6 and 7. Ammonia simulations for 1977 significantly underpredict the in-channel concentration. Two possible explanations are that 1977 was fairly dry, and thus concentration in the runoff is less diluted; the second explanation was experimental problems with the ammonia analysis (Cooper et al. 1987).

Pesticide calibration, verification, and simulation were performed for the insecticides DDT and Toxaphene. Figures 8 and 9 show long-term simulations for DDT at Stations 5A and 1. The simulations capture a significant portion of the long-term trends of DDT transport in Bear Creek. Figures 8 and 9 show the variability, over three orders of magnitude, for both the observed data and the simulations. The simulations show DDT in the runoff even though the insecticide was last applied around 1974.

## Conclusions

The HSPF model was applied to the Bear Creek watershed of the UYP. Calibration and

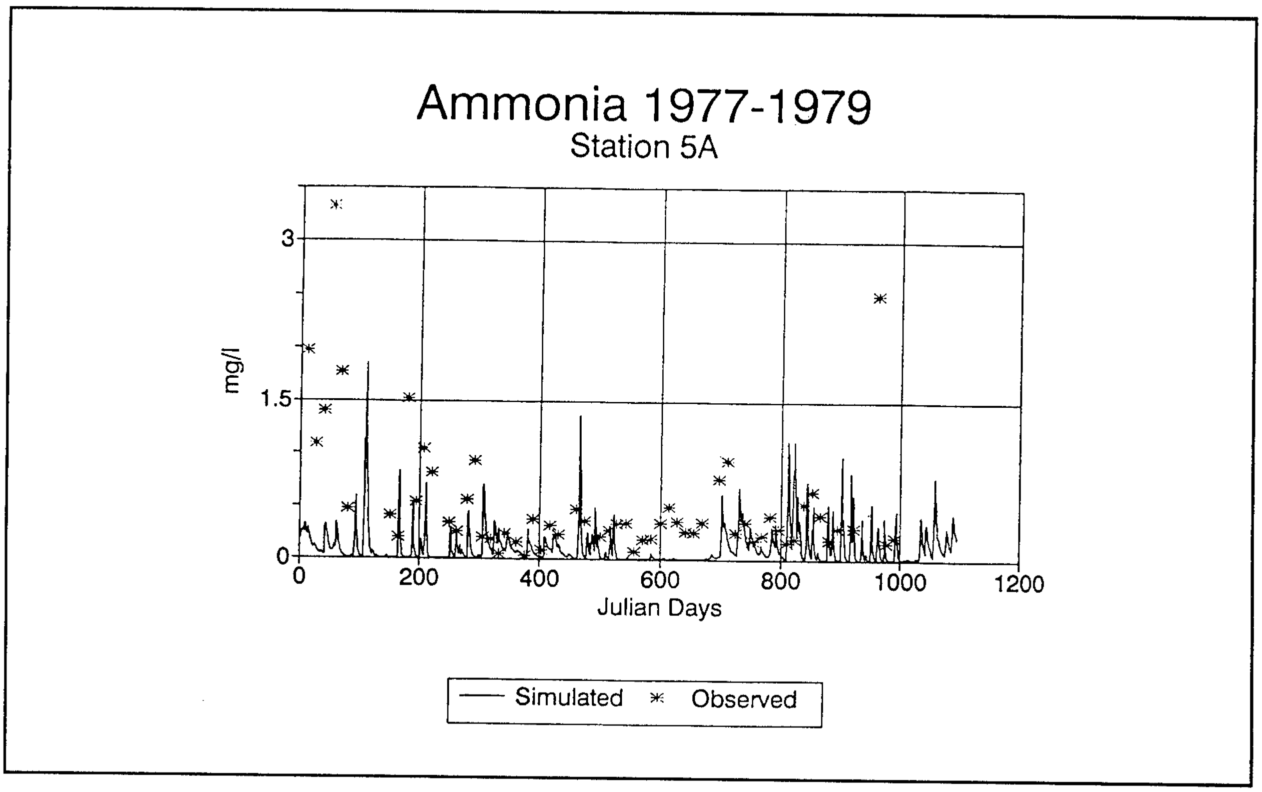


*Figure 6. Ammonia simulation for Bear Creek Station 5A, 1977-1979*

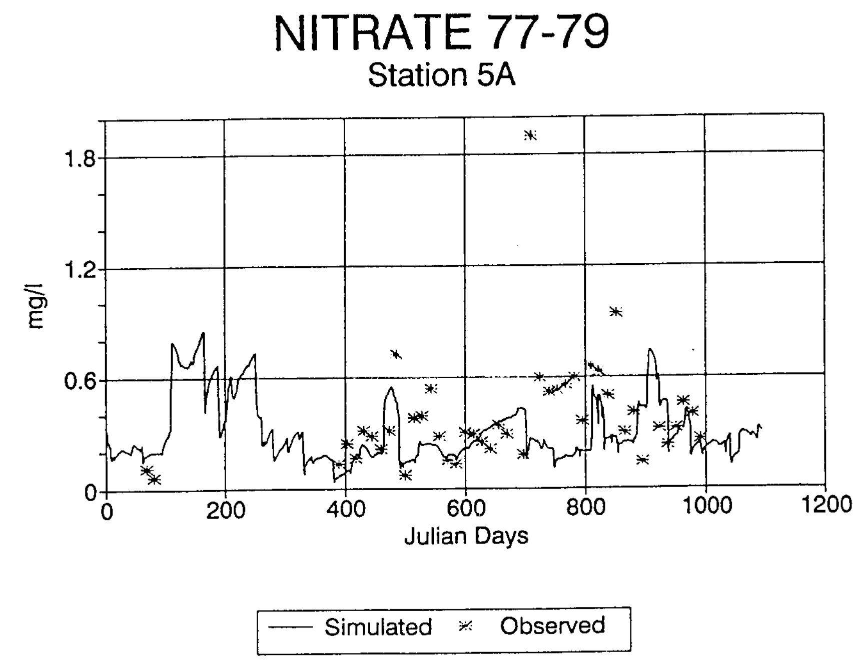


*Figure 7. Nitrate simulation for Bear Creek Station 5A, 1977-1979*

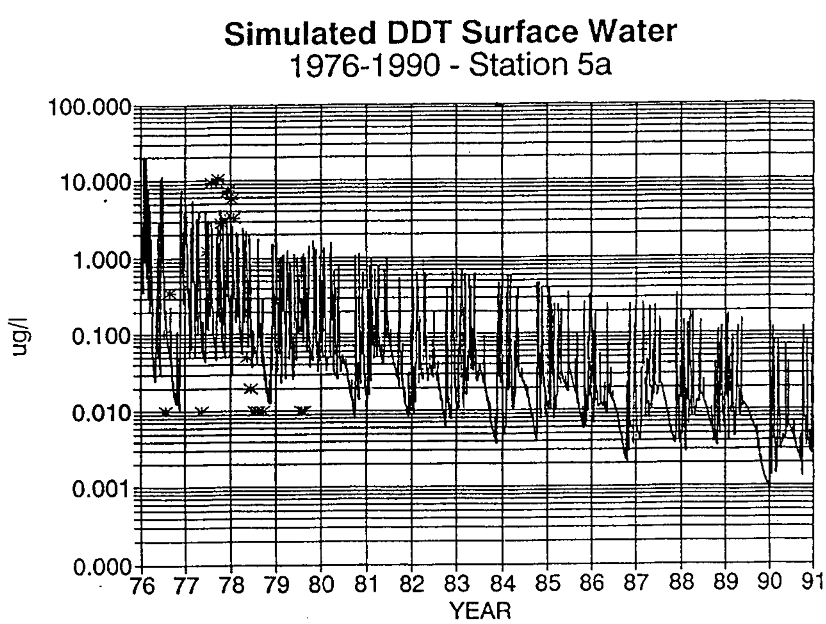


*Figure 8. Long-term DDT simulation for Bear Creek Station 5A, 1976-1990*

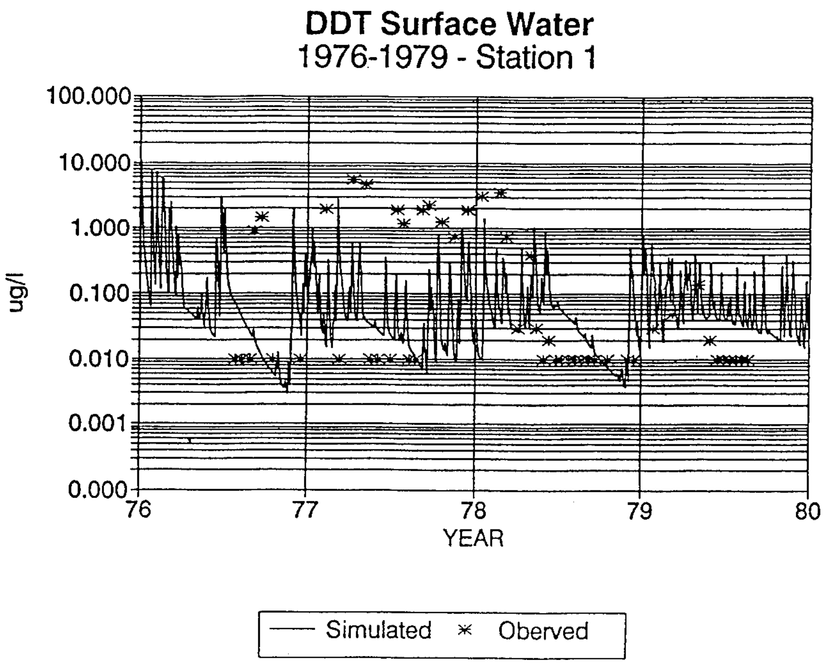


*Figure 9. DDT simulation for Bear Creek Station 1, 1976-1979*

verification of the model were successful. Overall, the model predicted both the short-term and long-term trends and transport of suspended sediment, nutrients, and pesticides in the Bear Creek watershed. The simulation results show that the calibrated model can be used to address land-use changes and impact of those changes in the water quality of Bear Creek or any other typical watershed in UYP.

## Acknowledgments


The authors greatly thank the Vicksburg District for providing the observed data necessary for the study. This study was funded by the Vicksburg District through a Military Interdepartmental Purchase. The Chief of Engineers has granted permission to publish this information.


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# Predicting Basin-Wide Tailwater Temperature Patterns by Combining Mechanistic and Statistical Water Quality Modeling

*by*
*John M. Nestler*[1] *and L. Toni Schneider*[1]

## Introduction

The U.S. Army Engineer Division, Missouri River, controls, maintains, and conserves water resources to provide for flood control, navigation, irrigation, power generation, recreation, water quality, water supply, and fish and wildlife protection and enhancement by regulating the releases from dams on the main stem Missouri River. Efforts by the Missouri River Division to continue fostering economic development in the basin, while simultaneously protecting environmental resources, requires credible models to screen alternative reservoir operating plans for their effect on downstream water temperatures. These models must be able to work within a basin-wide assessment framework to characterize water temperature patterns in tailwaters supporting temperature-sensitive fishes. That is, the models must have run times sufficiently short to predict complex temperatures downstream of multiple dams over decades-long hydrologic periods and also must be able to utilize low spatial and temporal resolution data associated with basin-wide analysis. These constraints preclude direct use of CE-QUAL-RIV1Q or similar complex numerical models to predict long-term temperature patterns.

Basin-wide assessment of all resources within the main stem Missouri River system regulated by Corps of Engineers (CE) dams are assessed using hydrologic predictions from the Long Range Study (LRS) model (U.S. Army Corps of Engineers 1992). This planning model predicts monthly stages and monthly discharges for each reservoir within the main stem system for a specific reservoir operational plan over a 93-year-long hydrological record. Using a simplified temperature modeling approach driven by variables associated with the LRS model allows Missouri River Division to couple the two models using linking programs. The Division then runs the LRS model and passes the output to a simplified temperature model that analytically computes the number of river miles meeting specific temperature criteria below each of the hydropower dams. The simplified temperature model, once verified, can also be used as a stand-alone or incorporated into a reservoir model.

## Methods

Development of a simplified method for predicting downstream water temperature patterns requires two steps.

### Step One

A one-dimensional longitudinal, time-varying, riverine water quality model, CE-QUAL-RIV1Q (Environmental Laboratory 1990), was used to predict water temperatures in the 50-mile tailwater downstream of Fort Randall Dam under incremental upstream boundary and meteorological conditions (Table 1) covering the range of conditions expected under revised operations. Hydraulic information necessary to drive the water quality model was provided by the UNET model (U.S. Army Engineer Hydraulic Engineering Center 1991) calibrated to measured stages and discharges provided by the Missouri River Division

[1] U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

(Nestler, Schneider, and Hall 1993). Representative tailwater temperature data for model calibration were collected at three stations downstream of Fort Randall Dam.

## Step Two

Downstream water temperature patterns predicted in step one follow patterns described by the logistics equation (a difference equation commonly used by ecological modelers)

$$T_x = K/(1+(((K-S)/S)*(EXP(-R*X)))) \qquad (1)$$

where

$T_x$ = water temperature at x miles from the dam

K = apparent temperature target in °C towards which the release temperature approaches as the releases flow downstream

S = discharge water temperature in °C

R = rate of temperature change

X = distance from the dam in miles

**Table 1**
**Combinations of Reservoir Discharges, Discharge Temperature, Equilibrium Temperature, and Ramping Pattern Used for Scenario Development (108 combinations)**

| Discharge cfs | Release Temperatures, °C | Equilibrium Temperatures, °C | Ramping Indices |
|---|---|---|---|
| 10,000 | 5 | 10 | 0.0,0.5,1.3,1.7 |
| 20,000 | 15 | 20 | 0.0,0.2,0.5,1.6 |
| 28,000 | 25 | 28 | 0.0,0.4,0.5,0.6 |

Note: For each scenario, release temperature and equilibrium temperature were held constant and flows were routed downstream based on a ramping index provided by the Missouri River Division. The ramping index is defined as the minimum daily discharge subtracted from the maximum daily discharge divided by the mean daily discharge. A representative daily ramping index was applied to each average monthly discharge based on historical power demand patterns.

The downstream temperature patterns associated with each of the 108 scenarios generated from step one were fitted to the logistics equation using PROC NLIN (SAS Institute 1988) to generate 108 observations having separate R and K coefficients and a series of independent variables that represented operation at the dam and meteorologic conditions. The R and K coefficients obtained by nonlinear regression were then linearly regressed against the independent variables (PROC REG - SAS Institute 1988). The resulting linear regression equations were coded into a short program that solved the reconfigured logistics equation

$$X = (-1.0/R)*LOG((1/((S-K)/K))*((K/T)-1)) \qquad (2)$$

where

T = user-selected temperature threshold in °C

X = miles from dam where temperature threshold is met

The program was linked to the LRS model and used as a simplified procedure to predict the length of tailwater providing water temperatures that met monthly, user-defined temperature criteria. Additional runs of the UNET and CE-QUAL-RIV1Q models, using boundary conditions different from those used to develop the regression relationships, were made to generate data to test the accuracy of the screening model.

# Results

## Step One

In general, predicted water temperatures matched field data calibration data at stations near the dam (e.g., Figure 1); but predicted temperatures deviated from measured temperatures by as much as 2.0 °C at the station 30 miles from the dam. Field inspection indicated that major bed changes in the lower reaches in the time between the collection of cross-section data and water quality calibration data probably caused the increased error between predicted and observed water temperatures in the lower reaches.

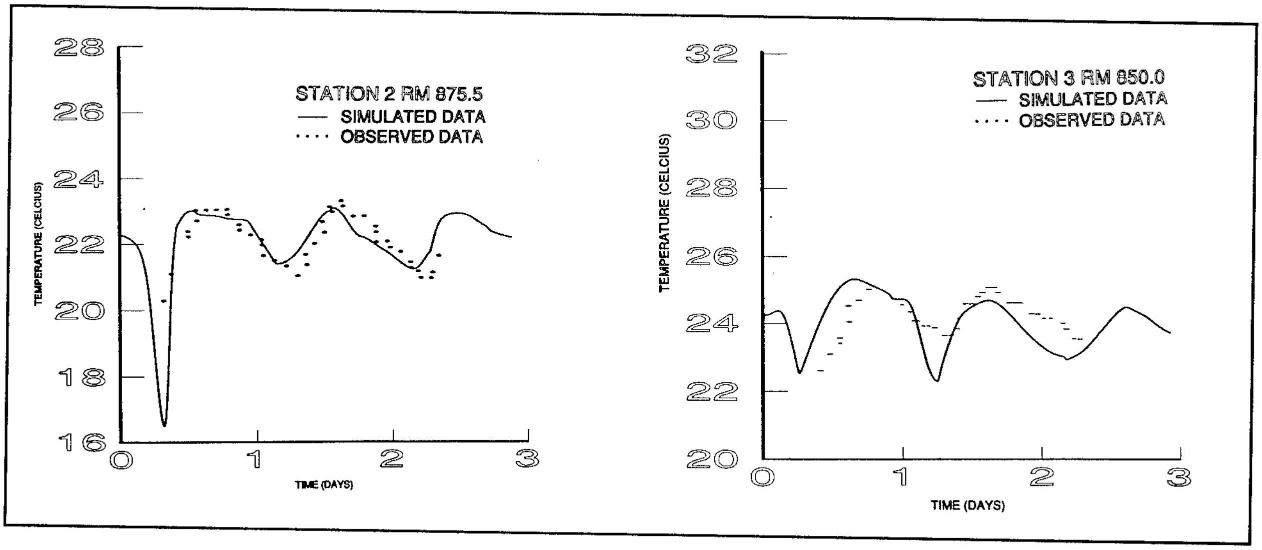


*Figure 1. Predicted and observed water temperatures 5.0 miles and 30 miles downstream of dam under peaking operation*

## Step Two

A good fit was observed between CE-QUAL-RIV1Q predicted water temperatures and the logistics equation for each of the 108 scenarios (e.g., Figure 2). The logistic equation provided a good fit (errors less than 1.0 °C) for downstream water temperatures when the minimum flow component of the ramping pattern was more than 6,000 cfs and the difference between equilibrium temperatures and release temperatures was less than 15.0 °C (not shown). Errors as large as 2.0 °C were observed when these conditions were violated. The error between verification downstream temperature patterns simulated by the water quality model, the fitted logistics equation, and the synthesized water temperatures obtained from regression equations were generally less than 1.0 °C (Figure 3) for three test cases.

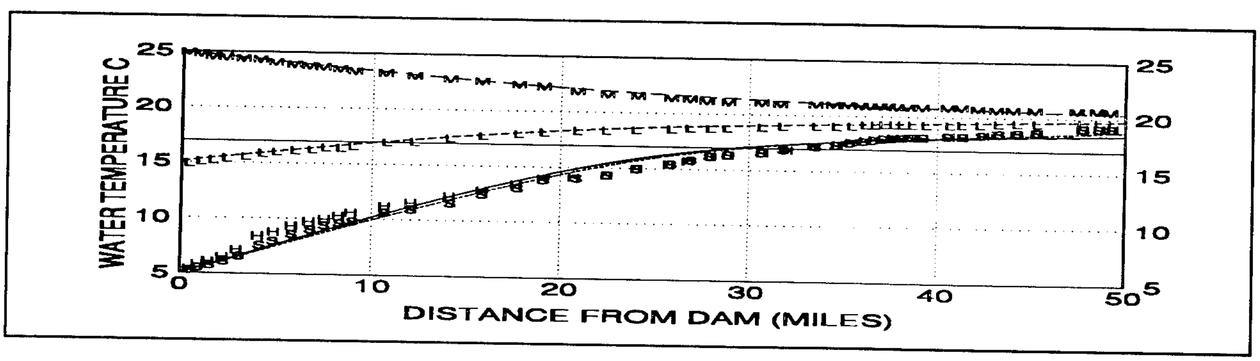


*Figure 2. Representative CE-QUAL-RIV1Q predicted temperatures (H, M, L, and S representing ramping indices of 1.62, 0.54, 0.21, and 0.00, respectively) fitted to the logistics equation (solid, long dash, short dash, and dotted line representing ramping indices of 1.62, 0.54, 0.21, and 0.00, respectively) for four scenarios for a discharge of 20,000 cfs and an equilibrium temperature of 20 °C. Reconfigured logistic equation with a coldwater temperature threshold of 17.0 °C (solid horizontal reference line) applied to middle line (L) would predict that 10.7 miles of tailwater would provide adequate temperature. Deviations between predicted and fitted temperatures increase at low release temperatures and high ramping indices. Maximum differences between modeled and fitted temperatures were 1.0 °C*

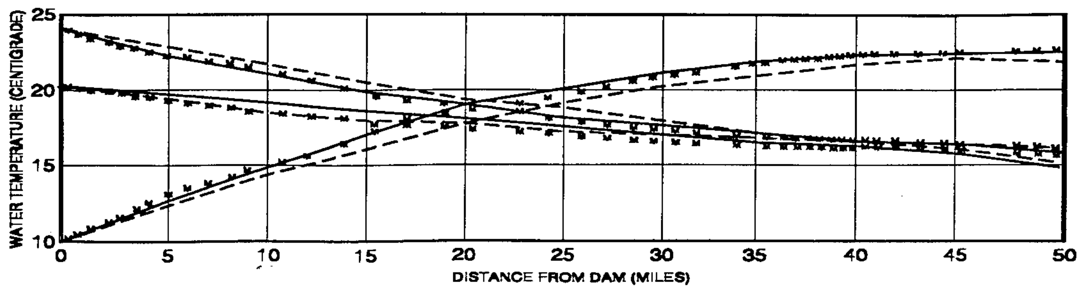


*Figure 3. Comparison of numerical model predicted (M), fitted (solid line), and synthesized (dashed line) downstream water temperatures*

## Discussion

A simple statistically based, analytical model for evaluating the effect of different operational alternatives on downstream water temperatures was developed by combining detailed mechanistic riverine water quality modeling with statistical analysis. The relatively simple output of the model, either a downstream water temperature pattern as described by the logistics equation or the length of tailwater meeting specific temperature criteria, facilitates evaluation of multiple dams over long periods of record in a basin-wide assessment. The predictive power of sophisticated numerical models will be more likely employed by decision makers if the patterns and trends of the predictions can be simplified using statistical techniques.

## Acknowledgments

The authors thank the U.S. Army Engineer District, Omaha, and the Missouri River Division for providing stage and flow data that were employed in this analysis. Mr. Brad Hall of the Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station (WES), performed the UNET modeling that provided hydraulic information for the water quality model. The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the Missouri River Master Water Control Manual Review of the U.S. Army Corps of Engineers by WES. Permission was granted by the Chief of Engineers to publish this information.

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# Bluestone Modeling Study

*by*
*Dorothy H. Tillman*[1] *and Thomas M. Cole*[1]

## Introduction

The U.S. Army Engineer District, Huntington, is presently considering raising the pool at Bluestone reservoir 11 ft and adding conventional, base-load hydropower. Through the Water Operations Technical Support (WOTS) program, the Huntington District contacted the U.S. Army Engineer Waterways Experiment Station (WES) Environmental Laboratory for recommendations on evaluating effects to water quality if the proposed modifications were made. WES recommended a three-phase approach as follows: (a) apply the SELECT model (Davis et al. 1987) to evaluate potential dissolved oxygen (DO) of release water with hydropower assuming no change in in-pool conditions, (b) apply the time-varying, two-dimensional (laterally averaged) hydrodynamic and water quality model, CE-QUAL-W2, to evaluate potential changes in in-pool and release temperature and DO assuming a gross water column oxygen demand for DO, and (c) apply CE-QUAL-W2 with all water quality state variables activated to more accurately define potential changes in future in-pool and release DO instead of having to make broad assumptions about the depletion rate.

Phase 1 of the Bluestone Water Quality Study was completed by personnel at the Huntington District with guidance from the WES Hydraulics Laboratory. The WES Environmental Laboratory conducted phase 2 as requested by the District. Results from phase 2 are presented in this paper.

## Study Objective

The Environmental Laboratory assisted the Huntington District by conducting the phase 2 numerical modeling of temperature and DO in Bluestone Lake, West Virginia. Model results from CE-QUAL-W2 scenario runs were used to evaluate potential changes in in-pool and release temperature and DO by raising the pool 11 ft and adding hydropower to the project.

## General Modeling Approach

This study involved applying the two-dimensional (laterally averaged) hydrodynamic and water quality model, CE-QUAL-W2, to Bluestone Lake for temperature and DO only. DO was modeled in a simplified manner using a gross water column oxygen demand (WCOD) and a sediment oxygen demand (SOD). The assumption in this approach is that the change in pool will not affect the WCOD and SOD rates, which cannot be confirmed without proceeding to the recommended third phase. The benefit of this study was to have more confidence and greater resolution (in terms of time discretization and accuracy of release DO results) than the first phase study recommended by WES in determining impacts.

Once CE-QUAL-W2 was calibrated and verified for a dry and wet year, respectively, two scenario runs were made: (a) raising the pool 11 ft and (b) raising the pool 11 ft and adding hydropower. Comparisons were made between calibration/verification results and

[1] U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

scenario results for both years to determine impacts to temperature and DO on in-pool and release concentrations.

## Calibration/Verification

The model was calibrated and verified for a dry and wet water year (1981 and 1983, respectively). Most of the data required for the study was provided by the Huntington District.

### Calibration

The water balance of Bluestone Lake has to be completed before actual calibration of temperature and DO could be conducted. Adjustments to the bathymetry data and the elevation of the bottom datum were made to correct water imbalances in the system. These parameters were adjusted until the predicted elevations and volumes satisfactorily matched the elevation-area-capacity data provided by the District. The predicted WSEL were well within the 0.5-m error (i.e., less than 0.1 m for short periods) considered acceptable (Environmental and Hydraulics Laboratories 1986).

Satisfactory results for hydraulic calibration allowed initiation of water quality calibration. Temperature was calibrated first since DO is temperature dependent. Table 1 lists the observed in-pool stations and the location of each in relation to Bluestone Dam. During temperature calibration, the initial boundary conditions for temperature were set to the

**Table 1**
**Observed Profile Stations**

| Station No. | Distance from Dam miles | Segment No. | 1981 | 1983 |
|---|---|---|---|---|
| 1BLN20002 | 0.25 | 31 | X | X |
| 1BLN20007 | 1.00 | 29 | X | |
| 1BLN20008 | 2.00 | 28 | X | X |
| 1BLN20003 | 2.90 | 26 | X | X |
| 1BLN20009 | 4.00 | 25 | X | |
| 1BLN20010 | 5.00 | 22 | X | X |
| 1BLN20011 | 6.00 | 20 | X | |
| 1BLN20012 | 7.00 | 18 | X | X |
| 1BLN20013 | 8.00 | 17 | X | |
| 1BLN20014 | 9.00 | 15 | X | X |

most upstream observed data (1BLN20014). To improve temperature predictions, adjustments were made to the chezy coefficient and wind-sheltering coefficient. They were initially set to values recommended in the user's manual (Environmental and Hydraulics Laboratories 1986). However, only after restricting the lower limit of selective withdrawal to elevation 1,387 ft, was the thermocline predicted correctly. For a reservoir having such a short retention time (approximately 6 days at the most), Bluestone temperature profiles showed more stratification than would be expected. For instance, hypolimnetic temperatures would have been expected to increase as the summer progressed. However, the observed data showed very small changes in hypolimnetic temperatures throughout the summer, especially in 1983. The reason for having to restrict selective withdrawal was unknown at the time of the study. However, in October 1993, District personnel investigated the probable cause by doing some velocity profiles and sounding at 20 and 100 ft upstream of the dam. They found that at the station closest to the dam there were no velocity measurements below approximately 22 ft. Divers found that the track racks had debris buildup on them possibly preventing withdrawal from lower levels (Figure 1). It was reasonable to conclude that this was the probable cause for having to restrict selective withdrawal.

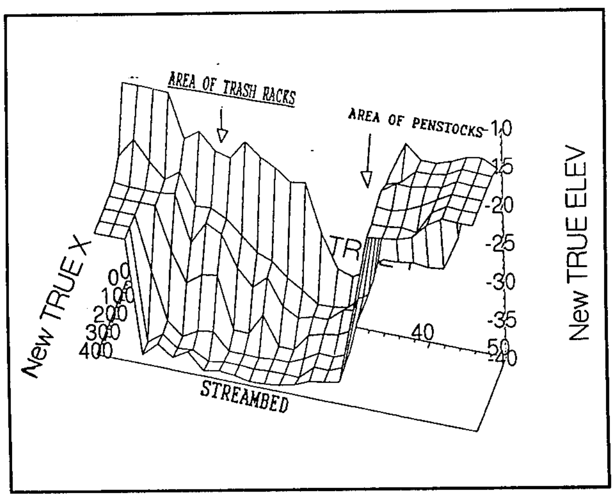


*Figure 1. Forebay streambed geometry at Bluestone Dam*

Although DO was modeled in a simplified manner, calibration results compared favorably with observed data. Since there were no observed inflow DO data available, DO boundary conditions were initially assumed to be saturated. Using saturated DO boundary conditions resulted in overprediction of the most upstream DO. DO boundary conditions were then set to the observed values at the most upstream station (1BLN20014). Initial DO predictions in the upper reaches were improved, which improved DO predictions in the downstream reaches as well.

Further calibration of DO required adjustments to the SOD and WCOD rates. Initially, they were set to values recommended in the CE-QUAL-W2 user's manual (Environmental and Hydraulics Laboratories 1986). The SOD and WCOD rates were not varied longitudinally, but were set the same for all segments. After adjusting the SOD and WCOD parameters, DO profiles were improved at some stations, but were worse at others. Since there are many factors (i.e., inflow, allochthonous inputs, algal photosynthesis and respiration, and wind) influencing DO concentrations throughout a reservoir (Cole and Hannan 1990), it was decided that SOD and WCOD rates should be varied longitudinally. DO profile predictions were then significantly improved throughout the reservoir.

Many of the disparities between predicted DO and observed profiles (especially in the epilimnion on 25 July 1981 and 25 August 1981, at stations 1BLN20002, 1BLN20007, 1BLN20008, and 1BLN20003) were attributed to algal production, which was not simulated by CE-QUAL-W2 during this phase of the study.

Assessment of model performance for release conditions was conducted by comparing predicted release conditions to observed conditions at a station 500 ft downstream of the dam. Release temperature for both years compared favorably with predicted values; however, predicted release DO was considerably lower than observed values. This was probably due to in part to reaeration that had occurred to the parcel of water sampled and the inability to predict the higher DO values in the epilimnion caused by algal production.

## Verification

During verification, inflow temperature and DO boundary conditions were set using the same procedure for calibration. All other parameters (e.g., chezy coefficient and windsheltering coefficient were also set the same as during calibration. This included having to restrict selective withdrawal at the same elevation to correctly predict the thermocline.

An acceptable water balance was obtained for verification. Verification temperature and DO profile predictions for all stations also compared favorably with the observed data. As in the case of calibration, many of the disparities between predicted and observed DO in the epilimnion (i.e., on 3 August 1983, at stations 1BLN20002, 1BLN20008, 1BLN20003, and 1BLN20010) were attributed to algal production. On 22 September 1983, DO predictions indicate overturn has occurred for most of the reservoir except at station 1BLN20002; however, this was not indicated by observed profile data. The exact date of overturn is difficult to predict because of limitations in meteorological data (i.e., met stations may be quite a distance from the project). As a result, predicted overturn is often a few days off from observed.

## Sensitivity Analysis

Sensitivity analyses were performed on the SOD and WCOD rates to assess the uncertainty of these parameters on results and conclusions. SOD and WCOD rates were increased and decreased 50 percent using the calibration/verification control data files. Comparisons were made between calibration/verification results and results from the sensitivity analyses. Results from the sensitivity analyses showed that DO in the model is most sensitive to values specified for WCOD.

## Scenario Results

Changes in in-pool and release conditions were assessed by comparing scenario results with calibration and verification results. Scenario 1 consisted of raising the pool 11 ft. Scenario 2 consisted of raising the pool 11 ft as well as adding hydropower. For all runs, no reaeration through the sluice gates or penstocks was assumed to occur. The only differences between the two scenarios was the location and dimensions of the intake structure. Selective withdrawal remained restricted during the scenario runs since calibration/verification runs indicated this was necessary to simulate the system.

Differences between calibration release results and scenarios 1 and 2 release results are shown in Figure 2. In Figure 2, differences were calculated as calibration temperature or DO minus scenario 1 temperature or DO (represented by the dotted line), and as calibration temperature or DO minus scenario 2 temperature or DO (represented by the dashed line). Similar difference plots for the verification year (1983) are shown in Figure 3.

Temperature profile results from scenario 1 for both years demonstrate that raising the pool 11 ft causes the thermocline to be shifted deeper in the reservoir. This causes the release temperatures for both years to be, on the average, cooler than calibration/verification results until around Julian day 220. Although the thermocline is deeper in the reservoir than during calibration and verification, with the higher pool, it is at a higher elevation in relation to the outlet, resulting in cooler water being withdrawn. After Julian day 220, temperature releases were, on the average, warmer (maximum difference 1.1 °C) than calibration/verification results. This was especially true for the dry year (1981). The mean release temperatures for the calibration, scenario 1, and scenario 2 simulations using 1981 input data were 24.92, 25.01, and 25.03 °C, respectively, and the mean release temperatures for the verification, scenario 1, and scenario 2 simulations using 1983 input data were 25.02, 24.86, and 24.84 °C, respectively.

DO profiles for both years for scenario 1 show that because of the deeper thermocline, higher DO values occur deeper in the reservoir. This is also seen in scenario 2 results. Differences in DO results indicate that, on the average, lower DO values (maximum difference approximately 5 mg/L for 1981 and 3 mg/L for 1983) were released for both scenarios in comparison with calibration/verification releases. The mean release DO concentrations for calibration, scenario 1, and scenario 2 simulations for 1981 were 5.43, 4.82, and 4.87 mg/L, respectively, and the mean release DO concentrations for verification, scenario 1, and scenario 2 simulations for 1983 were 5.88, 5.42, and 5.42 mg/L, respectively. Lower DO values were due to more of the hypolimnetic DO being available for withdrawal. The greatest DO difference between the two scenarios occurs between Julian day 255 and day 265 for both years. This difference may have resulted from the timing of overturn and the difference in the withdrawal zone caused by the different intake locations and dimensions.

## Conclusions

From the two scenarios simulated, the following conclusions were derived:

*a.* Temperature profiles for most stations (especially stations closer to the dam) showed deeper thermoclines resulting in higher DO values deeper in the reservoir. Release temperatures increased as much as 1.1 °C. Most of the higher release temperatures occurred during the latter half of the simulation for both years. Average release temperatures for the simulation period were similar in value between calibration/verification and the scenario results.

*b.* Decreases in release DO occurred throughout the simulation period for both scenarios. The average decrease

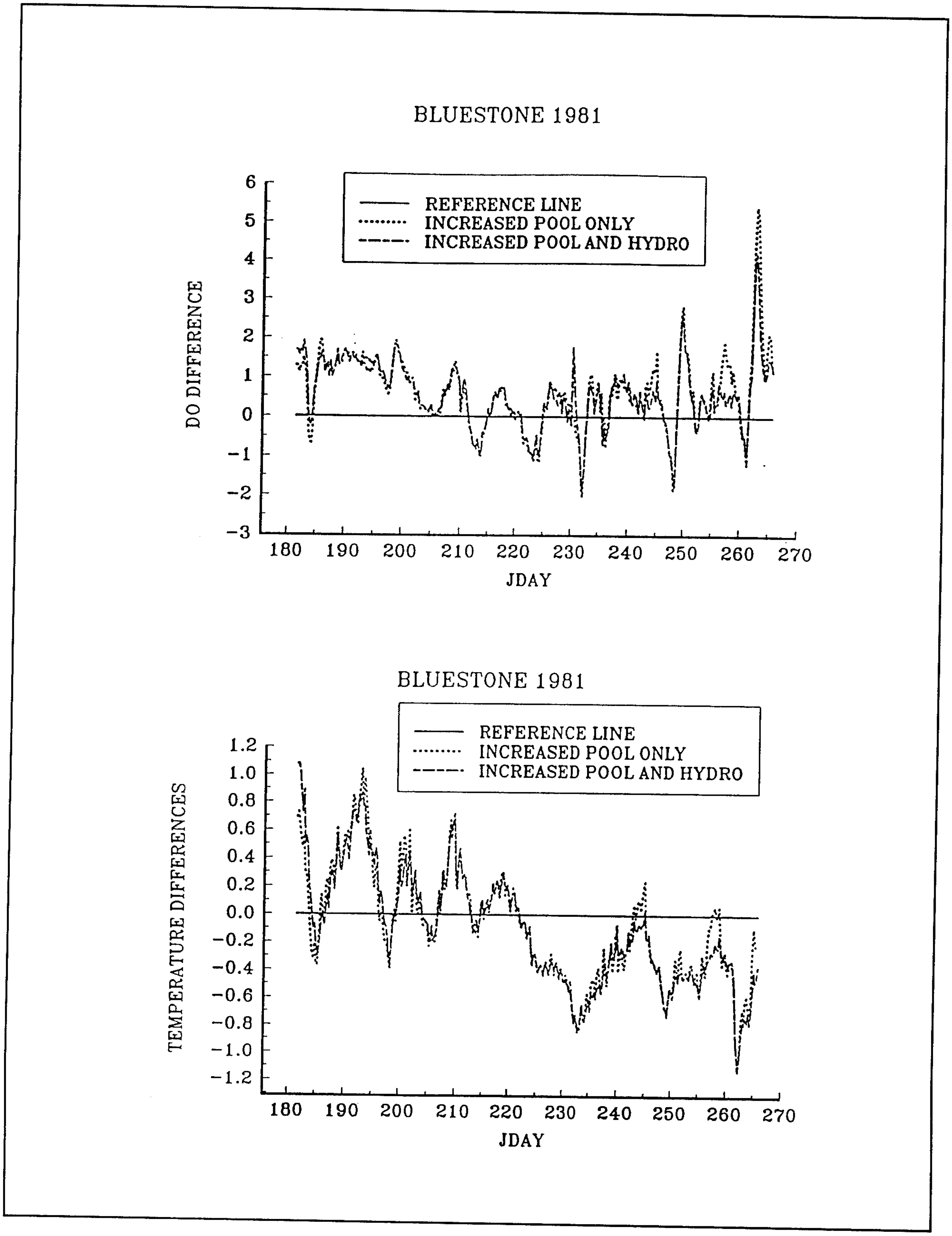


*Figure 2. DO and temperature differences between calibration results and both scenario results*

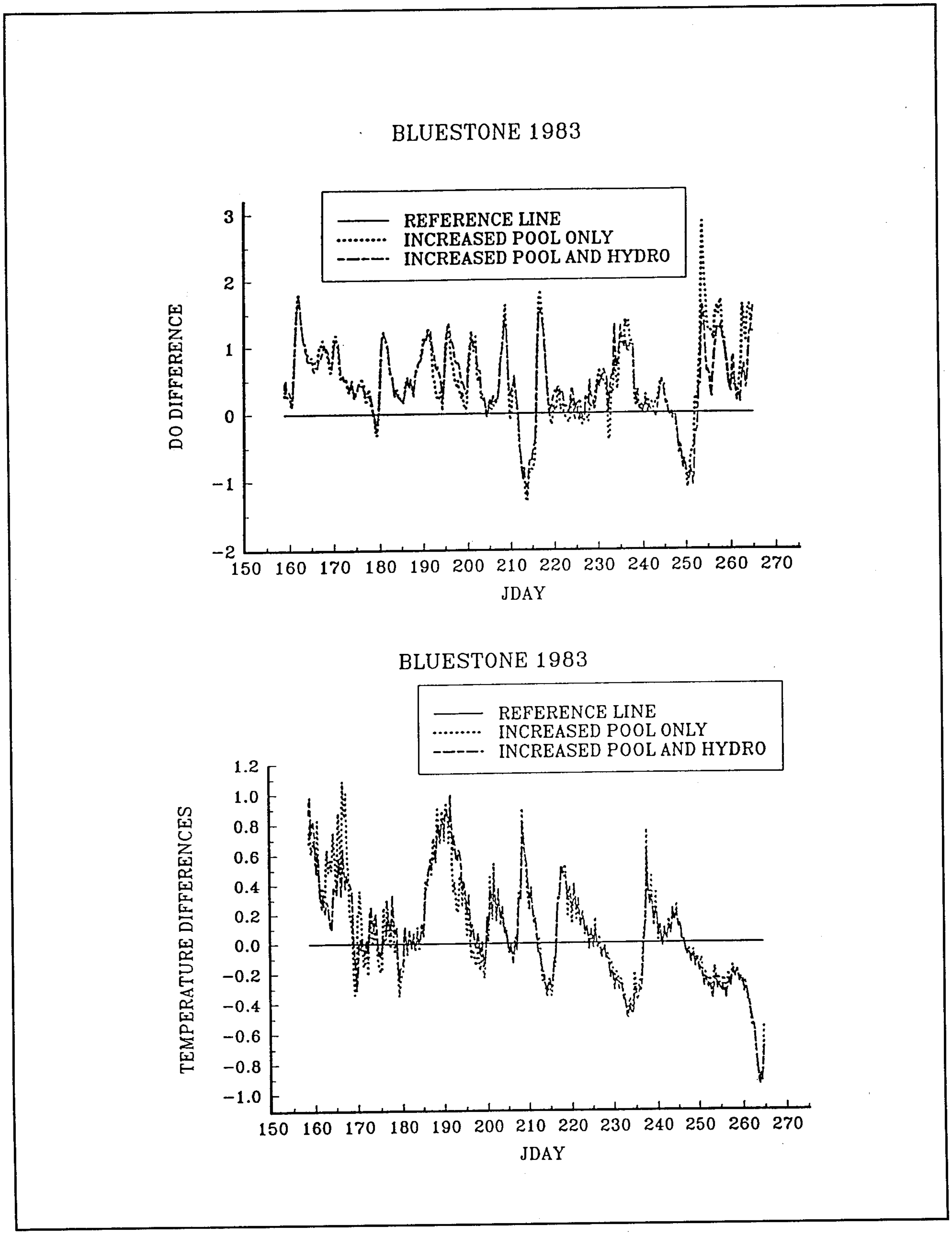


*Figure 3. DO and temperature differences between verification results and both scenario results*

in DO releases was approximately 0.6 mg/L for both years.

*c.* The addition of hydropower (scenario 2) did not significantly affect temperature and DO results when compared with scenario 1 results. Because the reason for having to restrict selective withdrawal was unclear, late in the study, runs were made without restricting selective withdrawal. Temperature profile results for both years showed very little thermal stratification. In addition, DO profile concentrations were also higher deeper in the reservoir, but the mean release DO concentrations were about the same as scenario 2 results.

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# Scope of Corps Involvement with ORSANCO

*by*
*Joseph E. Svirbely*[1]

## Introduction

### Background

Sixty years ago, the water quality of the Ohio River could best be described as poor. Only a few of the urban centers along the river were sewered. It was reported in 1930 that because of drought, the navigational pools formed by Government dams along the river were "open cesspools." During the 1930 drought, outbreaks of gastroenteritis along the river were prevalent.

In response to public pressure, the U.S. Congress in 1936 authorized the States of the Ohio River Valley to negotiate a compact to address pollution of the Ohio and its tributaries. In 1948, this compact, which was approved by U.S. Congress and ratified by the eight States of the basin, created the Ohio River Valley Water Sanitation Commission (ORSANCO).

### Rationale for Ohio River Division Support for ORSANCO

The rationale for the U.S. Army Engineer Division, Ohio River, support for ORSANCO and for their frequent interaction is found in their common mission—the restoration and management of water quality in the Ohio River and its tributaries.

## Division Interactions with ORSANCO

### Ohio River Division Staff Participation on ORSANCO Committees

The Compact that created ORSANCO provides that the Commission consist of 27 members—three Commissioners from each of the eight States and three representing the Federal Government, appointed by the President. This joint membership of the States and the Federal Government is reflected on the committees that advise the Commission and carry out its charges.

The Corps is currently represented on the Technical Committee, two of its subcommittees, and the Emergency Response Coordinators Group. In addition to a representative of the Corps, the Technical Committee has members from each of the eight States, the U.S. Geological Survey, and the U.S. Environmental Protection Agency. The Technical Committee meets three times a year and oversees ORSANCO's technical programs, ensuring that they are coordinated with programs of the members' agencies. ORSANCO programs fall into four general areas—water quality monitoring, water quality assessment, emergency response, and pollution control.

1 U.S. Army Engineer Division, Ohio River; Cincinnati, OH.

The Monitoring Strategy Subcommittee and the Biological Monitoring Subcommittee each have a member from the Corps. These subcommittees meet once or twice a year and advise the Technical Committee on the direction of the ORSANCO monitoring programs. Corps representatives from Construction-Operations and Water Management in the Division office also participate in the Emergency Response Coordinators Group, which meets yearly.

## Water Quality Monitoring

From 1961 to 1986, ORSANCO maintained a network of water quality monitors on the Ohio River and its tributaries. By 1986 when ORSANCO terminated the monitoring network, they had 24 water quality monitors. In addition, ORSANCO maintained Corps water quality monitors on the river; even though ORSANCO maintained these Corps monitors, the Corps never lost its own monitoring capability. Although hard pressed in 1987 and 1988 after ORSANCO ended their effort, the Corps network provided valuable data that helped push through the lower Mononghahela renovation. Because the monitor upstream from Locks and Dam 3 demonstrated that the utility located in Pool 3 was flagrantly out of compliance for water temperature violations even with a variance, the utility could not win a lawsuit to prevent removing Locks and Dam 3 claiming they would lose their variance.

The Corps Districts depend on the network of 12 water quality datasondes monitoring dissolved oxygen concentration, water temperature, pH, and specific conductivity at projects on the Ohio River and major tributaries from Lock and Dam 3 on the Allegheny River at Acmetonia, PA, to Smithland Locks and Dam near the confluence with the Cumberland River. In addition, there are datasondes on minor tributaries and reservoir projects measuring water temperature and in some cases dissolved oxygen concentration and pH. The data provided by this network yield information necessary to make operational decisions regarding augmentation to meet temperature, pH, and dissolved oxygen targets throughout the Division as well as forming a database that is used to implement antidegradation policy.

Valid data on water quality conditions of the Ohio River are essential to the efforts of ORSANCO in carrying out the provisions of the Compact. ORSANCO depends on the Corps monitors for real time dissolved oxygen concentration and temperature readings on the Ohio River from May to October, when Division files are downloaded weekly using programs written by the Ohio River Division to facilitate ORSANCO utilization of data. When dissolved oxygen concentrations or temperature violate target levels at hydropower projects, emergency procedures are initiated, including communication with hydropower operators to rectify the problem, interaction involving the Corps and utilizing its memorandum of understanding with the utility, and in rare cases regulatory action involving the utility operators. Data from nonhydropower projects are available to indicate water quality conditions in the absence of hydropower and in the Ohio River in general during the low-flow season.

## Pollutant Spill Response

ORSANCO serves as a communications link between various State and Federal agencies for spills on the Ohio River and its tributaries. Reports received by District offices are forwarded to the Ohio River Division, which reports the spill to ORSANCO. Likewise, if a spill occurs on the Ohio River or its tributaries and is reported to ORSANCO, a notice is put out on the ORSANCO electronic bulletin board where it can be accessed by the Ohio River Division. ORSANCO also coordinates spill response with Corps District offices when the need arises.

In addition, ORSANCO provides estimates of instream pollutant concentrations and time-of-travel studies that may be factored into Corps operational decisions regarding maintenance of flow at projects on the Ohio and its tributaries during a spill event.

## Zebra Mussel Reports

ORSANCO serves as the point of contact for reports of zebra mussel infestation in the Ohio River basin. Reports received by District offices are forwarded to the Ohio River Division zebra mussel point of contact who reports the incident to ORSANCO. Notices are placed on the ORSANCO electronic bulletin board and can be downloaded by interested parties including personnel at the Ohio River Division.

## ORSANCO Participation at Division Water Quality Workshop

The Ohio River Division and its Districts meet annually in the fall to discuss the events of the past year, compare notes, and share experiences. This meeting reenforces the sense of common purpose and teamwork that has grown up over the years at the Division.

A representative from ORSANCO is invited to this workshop each year. Time is set aside on the program for ORSANCO to describe the events of the year in the basin from their unique vantage point.

# District Interactions with ORSANCO

## Lock Chamber Studies

From 1975 to 1992, District water quality offices participated in lock chamber studies directed by ORSANCO at projects along the Ohio River and its tributaries. The entire Corps water quality staff of the Pittsburgh District was on hand every year with the Corps boat to sample locks at Mononghahela #2 near Braddock, PA, Dashields Locks and Dam, New Cumberland Locks and Dam, and Pike Island Locks and Dam. On alternate years, Maxwell Locks and Dam, Allegheny #8, Montgomery Locks and Dam, and Emsworth Locks and Dam were also sampled.

Rotenone was used to collect fish in the locks where they were collected and examined for diversity and productivity. In addition, fish fillets were taken and analyzed for contaminants. In 1991 and 1992, night electrofishing was also performed. Huntington District and Louisville District also participated on a frequent basis at locks in their Districts, especially when ORSANCO staff were short-handed or needed a boat. A moratorium was placed on lock chamber studies for 1993 to allow for more complete assessment and evaluation of lock chamber data.

## Ashland Oil Spill

At 9:30 p.m., Saturday, 2 January 1988, ORSANCO staff was notified by the Pennsylvania Department of Environmental Resources (PADER) that a spill of diesel fuel to the Mononghahela River at the Ashland Oil Company's Floreffe Terminal had occurred as a result of a ruptured storage tank. The precise amount of contaminant spilled was unknown. Through further reports received over the subsequent 2 days, it was learned that the spill could not be contained within Pennsylvania waters and that an interstate response was necessary.

Two types of monitoring took place during the event: monitoring at intakes to protect water supplies and monitoring of the Ohio River to define spill mass and track the spill movements. Tracking efforts were hampered by severe cold and a rain event on 19 January 1988 that increased flows and made time-of-travel modeling difficult.

A group at the command center including the U.S. Environmental Protection Agency (USEPA), National Oceanic and Atmospheric Administration, PADER, and ORSANCO initially sampled river water at the first eight water supply intakes downstream of the spill site. On January 6, USEPA, West Virginia Department of Natural Resources, and ORSANCO

initiated a program of sampling the spill from a towboat equipped with a fluorometer.

On January 16, personnel from the Corps' Huntington District assumed a primary role in obtaining field measurements utilizing a Corps boat and a flow-through fluorometer. Spill tracking by the Huntington District continued through 23 January when the spill passed Meldahl Locks and Dam (River Mile 436) and moved into the Louisville District. Louisville tracked the spill until 2 February, at which time the spill was no longer detectable by the boat-mounted fluorometer.

The spill was then tracked by stationary fluorometers at water intakes in order to provide water utilities with precise information concerning arrival and passage of the spill. Monitoring at Cairo, IL, concluded on 12 February 1988.

### River Sweep

With increased recreational use of the Ohio River, more and more litter is deposited, which can have a direct impact on water quality and indirectly gives the impression that water quality is being neglected. In 1989, ORSANCO organized the first Ohio River Sweep to promote public awareness and educate the public about the litter problem especially as it relates to water quality. One Saturday was set aside in June to take action and remove litter from the shoreline. More than 1,000 volunteers including Corps personnel and their families participated, cleaning 150 miles of shoreline from Cincinnati, OH, to Ashland, KY.

Because the program was so successful, the next year ORSANCO expanded the project to include the entire Ohio River shoreline (approximately 2,000 miles). At some sites, the Corps brought boats to get to areas that were not accessible to the volunteers. They also donated other equipment to help with the heavier litter.

The program has grown each year. More that 100,000 people have become involved, and more than 65,000 tons of trash and debris have been removed from the Ohio River shoreline. The Ohio River Sweep has garnered national awards and even a song was written to remember the event.

## Conclusion

It is evident from these examples that ORSANCO and the Corps of Engineers have built up mechanisms for teamwork to restore and manage water quality in the Ohio River and its tributaries.

The author gratefully acknowledges the assistance of Mr. Jerry Schulte and Ms. Jeanne J. Ison, Ohio River Valley Water Sanitation Commission, Mr. Mike Koryak of Pittsburgh District, Mr. Bill Cremeans of Huntington District, and Mr. Bill Easley of the Louisville District in the preparation of this paper.

# Use of the Tiered Testing Approach in Water Quality Evaluations

*by*
*David R. Johnson*[1] *and David L. Wallace*[1]

In 1991, the U.S. Army Engineer District, Vicksburg, was tasked to complete a Feasibility Study for the Red River Waterway, Shreveport, LA, to Daingerfield, TX, Reach. Alternatives for the navigation project consisted of various locations of locks and dams and locks in existing dams as well as navigational channel construction. The most feasible alternative plan consisted of constructing one lock and dam, and two locks added to existing dams, and 78 miles of channel construction through miles of environmentally sensitive areas. Because of the lack of available upland disposal sites and long pumping distances, the channel construction would likely require in-lake disposal sites. Project feasibility studies had been completed twice before, once by the New Orleans District and once by the Fort Worth District. The project was opposed by the U.S. Environmental Protection Agency (USEPA), the Fish and Wildlife Service (FWS), the Sierra Club, and various State agencies in Texas and Louisiana. Before the study initiated, the FWS called the project "the most environmentally damaging project ever attempted in Texas."

The project was a very controversial one and was environmentally sensitive because of the fact that Big Cypress Bayou below Lake O' The Pines is a natural and scenic river. The Big Cypress valley contains some of the only remaining bottomland hardwoods in Texas. Caddo Lake is the only natural lake in Texas and is often called the "Everglades of Texas." The whole study area was considered pristine and unique by most environmental groups. In contrast, the FWS and State agencies considered the area highly polluted. The FWS claimed both lakes were contaminated with polychlorinated biphenyls (PCBs), and local residents claimed that Caddo Lake had turned red from the discharge of pollutants from the munitions plant on its shores. The State of Texas claimed that the sediments of Lake O' The Pines were contaminated with heavy metals, which would pollute local water supplies if disturbed. Finally, Caddo Lake contains many oil wells, and residents feared that oil residues would be disturbed and pollute their water supply.

In the initial FWS Coordination Report, the FWS requested $250,000 for bioassays and fish tissue assays. This request was not in line with the planned water quality evaluation. The planned study consisted of obtaining monthly in situ and nutrient samples from nine stations and 30 sediment and water samples across the basin. In light of the intense local interest and the FWS request, a study design based on the "Tiered Testing Approach" was adopted. The tiered approach would allow study efforts to increase as needed, but avoid unnecessary up-front costs.

The "Tiered Testing Approach" was developed jointly by the U.S. Army Engineer Waterways Experiment Station (WES) and the USEPA and is included in the current Ocean Disposal Manual for 404 (b)(1). The Vicksburg District aimed to obtain two goals with the tiered approach, acceptability and fiscal restraint. The tiered approach includes these elements (WES 1988):

**Tier I** Initial evaluation of existing information and "reason to believe there is contamination."

**Tier IIA** Bulk sediment inventory.

[1] U.S. Army Engineer District, Vicksburg; Vicksburg, MS.

**Tier IIB** Elutriate analysis.

**Tier III** Biological tests.

**Tier IIIA** Acute bioassay toxicity tests: water column and/or benthic.

**Tier IIIB** Bioaccumulation: water column and/or benthic.

A Tier I background study did find that PCBs had been detected in the late 1970s in both lakes (Texas Water Quality Board 1977). An earlier Corps study had detected TNT and its derivatives in Twelve Mile Bayou below Caddo Lake (U.S. Army Corps of Engineers 1985). Thus the criteria "the reason to believe the sediments may be contaminated," was met, and a Tier IIA study was justified.

A sampling program was designed to evaluate general existing conditions. Nine stations were monitored monthly over a 1-year period by the U.S. Geological Survey (USGS). In addition, intensive sediment and water samples were collected by the Vicksburg District along the waterway. Over 30 samples were collected in areas where local concern had been expressed and past contaminants had been reported. Figure 1 shows the sampling stations used during this initial study.

Since there are no sediment quality criteria with which to evaluate sediment quality, these sediments were compared with two benchmark levels, ER-L and ER-M, reported by the National Oceanic and Atmospheric Administration (NOAA) (1990). These benchmarks were used as a comparison only and to help establish if there was a reason to believe that these sediments were contaminated. The ER-L represents the 10th percentile level of accumulated environmental effects data. It represents a low-level benchmark, and sites with concentrations below this level would not be considered contaminated and no further evaluation would be required. The ER-M represents the 50th percentile of the range of contaminant levels that produce environmental effects. Sediment concentrations in excess

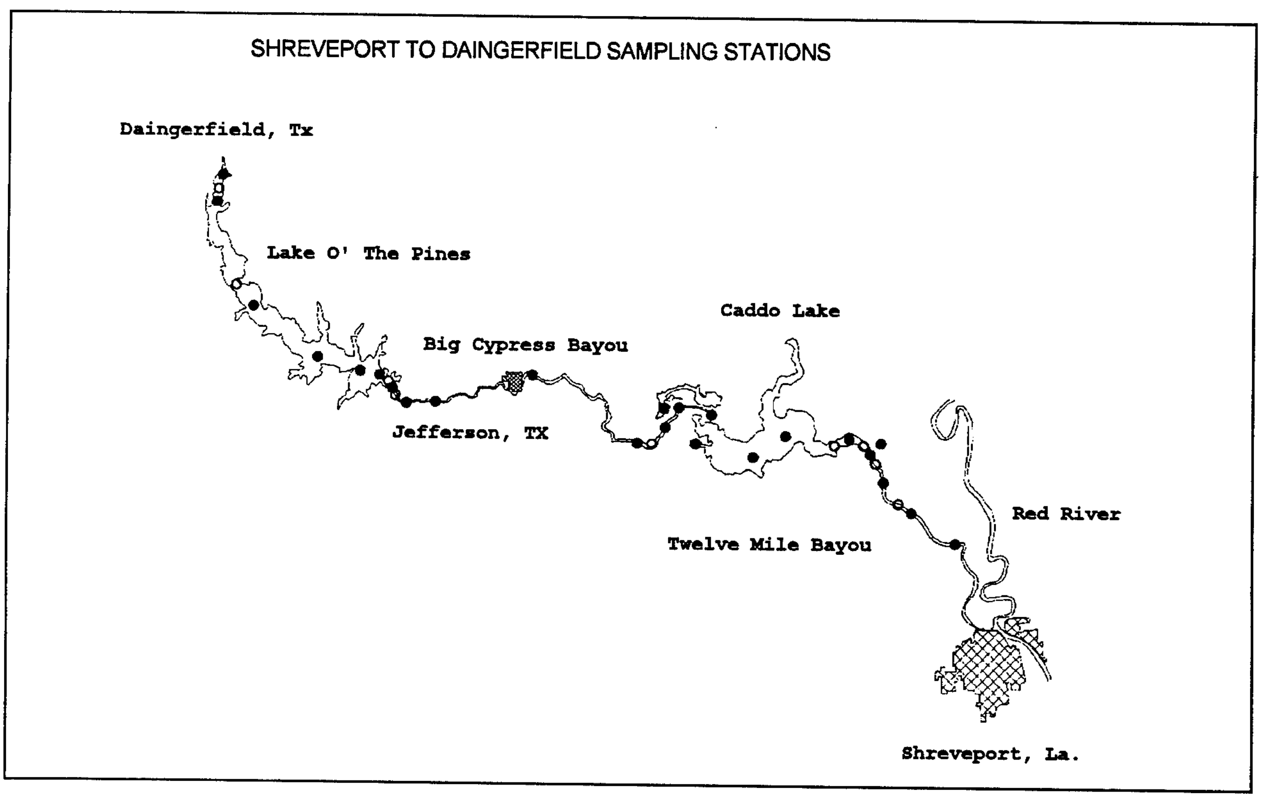


*Figure 1. Sampling stations*

of the ER-M could be considered contaminated. Concentrations falling between the ER-L and ER-M benchmarks are within a level of concern and should be thoroughly evaluated.

A few of the initial 30 sediment samples indicated elevated levels of some heavy metals in both lakes, and trace levels of several polycyclic aromatic hydrocarbons (PAHs) were detected in only one sample. No TNT or PCBs were detected in any of the samples (Tables 1 and 2). The benchmarks indicated that some heavy metals and the trace quantities of PAHs exceeded the ER-Ms and that further tests were needed to determine the areal extent of these contaminants. It was decided that further Tier IIA and Tier IIB samples were needed. Sediment cores were collected for the final Tier II samples to evaluate the extent of the elevated levels of heavy metals and PAHs. Results of these tests are shown in Tables 3 and 4. Figures 2, 3, and 4 compare the results of the sediment concentrations with the benchmarks used in this study.

The concentrations of several metals in the sediment cores were very high, in particular cadmium, lead, and zinc exceeded their respective ER-Ms, while arsenic and mercury levels exceeded their respective ER-L benchmark.

**Table 1**
**Mean Concentrations of Intensive Water Samples**

| Water Quality Parameter | Lake O'P-ines | Big Cypress Bay-ou | Caddo Lake | Twelve Mile Bay-ou | Criteria |
|---|---|---|---|---|---|
| Chloride, mg/L | 13.1 | 9.6 | 9.9 | 86.0 | 185 |
| Total Organic Carbon, mg/L | 4.0 | 3.2 | 4.0 | 3.9 | |
| Total Phosphorous, mg/L as P | 0.20 | 0.01 | 0.26 | 0.02 | |
| TKN- Nitrogen, mg/L as N | 0.81 | 0.53 | 0.94 | 0.79 | |
| Nitrogen - NO2-NO3, mg/L as N | 0.12 | 0.06 | 0.05 | 0.05 | 10 |
| Ammonia Nitrogen, mg/L as N | 0.04 | 0.04 | 0.01 | 0.02 | |
| Metals, total, µg/L | | | | | |
| Arsenic | 23 | <5.0 | 8.0 | 9.0 | 50 |
| Barium | 66.7 | 62.7 | 63.8 | 133 | 1000 |
| Cadmium[1] | 0.3 | 0.3 | 0.2 | 1.4 | 10 |
| Chromium | 6.2 | 27 | 7.4 | 1.7 | 50 |
| Copper[1] | 26.2 | 7.7 | 8.8 | 63.2 | 12[2] |
| Iron | 1,256 | 843 | 1,474 | 1,002 | 300[3] |
| Lead[1] | 4.3 | 2.3 | 2.0 | 2.5 | 50 |
| Manganese | 382 | 523 | 393 | 253 | 50[3] |
| Mercury | 0.3 | <0.2 | 0.2 | 0.3 | 2 |
| Nickel[1] | 10.2 | 4.1 | 12.4 | 2.2 | 160[2] |
| Zinc[1] | 74.4 | 26.0 | 28.8 | 37.2 | 110[2] |

Note: All criteria are drinking water standards unless noted otherwise.
1 Criteria are based on a hardness of 100 mg/L as $CaCO_3$.
2 Criteria listed are for the protection of chronic freshwater aquatic life.
3 Criteria listed are for the safe human consumption of water and fish.

**Table 2**
**Mean Concentrations of the Intensive Surface Sediment Survey**

| Sediment Parameter | Lake O' Pines | | Big Cypress Creek | | Caddo Lake | | Twelve Mile Bayou | | ER | |
|---|---|---|---|---|---|---|---|---|---|---|
| Units = mg/kg | Avg | Max | Avg | Max | Avg | Max | Avg | Max | ER-L | ER-M |
| TOC | 10,994 | 21,975 | 4,927 | 13,191 | 19,288 | 39,440 | 5,932 | 11,463 | | |
| Arsenic (0.1-40) | 5.9 | 11.8 | 3.19 | 12.8 | 5.0 | 11.2 | 1.94 | 3.67 | 33 | 85 |
| Barium | 142 | 244 | 43.8 | 157 | 169 | 329 | 181 | 328 | | |
| Cadmium (0.1-0.7) | 1.86 | 5.50 | <0.4 | <0.9 | 0.89 | 1.90 | 0.52 | 0.60 | 5 | 9.0 |
| Chromium (5-3000) | 19.8 | 40.8 | 5.35 | 16.6 | 18.7 | 36.5 | 13.2 | 19.3 | 80 | 145 |
| Copper (2-100) | 14.1 | 35.8 | 1.60 | 5.7 | 12.8 | 37.1 | 6.10 | 9.20 | 70 | 390 |
| Iron (7,000-550,000) | 27,300 | 47,900 | 6,762 | 21,300 | 28,400 | 53,700 | 14,100 | 20,500 | | |
| Lead (2-200) | 61.5 | 170 | 9.6 | 23.6 | 28.8 | 58.9 | 13.2 | 25.3 | 35 | 110 |
| Manganese (100-4,000) | 782 | 1,280 | 200 | 543 | 1,780 | 12,400 | 385 | 591 | | |
| Mercury (0.01-0.3) | 0.176 | 0.405 | <0.1 | <0.1 | 0.132 | 0.262 | <0.1 | <0.1 | 0.15 | 1.3 |
| Nickel (10-1,000) | 14.5 | 28.8 | 3.19 | 12.8 | 20.3 | 39.3 | 12.2 | 18.1 | 30 | 50 |
| Zinc (10-300) | 216 | 568 | 17.1 | 62.9 | 88.1 | 160 | 32.4 | 47.7 | 120 | 270 |

Ranges in parentheses are typical ranges within uncontaminated soils (Bowen 1966).

Elutriate results identified several metals that may elute to levels exceeding safe drinking water criteria; these included arsenic, barium, cadmium, copper, iron, and lead. PAHs were detected only in the most upstream section of the waterway. Based on the findings of the final Tier II tests, Tier III testing is needed. Testing for acute water toxicity in both lakes for heavy metals and acute sediment toxicity for heavy metals and PAHs in upper Lake O' The Pines would be required.

## Conclusions

The Tiered Testing methodology provided a logical approach to locating and identifying the major contaminants of concern, heavy metals and several PAHs. The Tiered Testing methodology effectively isolated the contaminated sites and provided the necessary data to prepare the Environmental Assessment. Because of the elevated concentrations of heavy metals and PAHs, further Tier III testing would have been necessary in the upper portion of Lake O' The Pines and mid lake of Caddo Lake. No toxicity testing for PCBs and TNT would have been required. A midpoint review of the project determined that the waterway was not economically nor environmentally sustainable, and further requirements for the next tier of sampling were terminated.

**Table 3**
**Sediment Core Metal Data**

| Station | Depth | TOC | AS | BA | CD | CR | CU | FE | MN | PB | HG | NI | ZN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake O' The Pines Sediment Core Data** | | | | | | | | | | | | | |
| ER-M<br>ER-L | | | 85<br>33 | | 9<br>5 | 145<br>80 | 390<br>70 | | | 110<br>35 | 1.3<br>0.15 | 50<br>30 | 270<br>120 |
| LPC2-1 | 0-4 | 470 | 8.1 | 160 | 1.29 | 17 | 14 | 2600 | 1100 | 84 | 0.20K | 16 | 280 |
| LPC2-2 | 4-8 | 5800 | 3.5 | 180 | 0.25 | 15 | 8.9 | 21000 | 1300 | 21 | 0.15K | 13 | 66 |
| LPC3-1 | 0-4 | 5700 | 5.6 | 200 | 4.54 | 25 | 27 | 30000 | 1000 | 150 | 0.29K | 20 | 480 |
| LPC3-2 | 4-8 | 7900 | 8.5 | 190 | 3.96 | 23 | 26 | 31000 | 730 | 140 | 0.29K | 20 | 510 |
| LPC3-3 | 8-12 | 3300 | 3.5 | 91 | 0.91 | 6.6 | 5.2 | 13000 | 180 | 34 | 0.15K | 5.1 | 140 |
| LPC3-1A | 0-4 | 4400 | 6 | 180 | 2.73 | 20 | 23 | 29000 | 1200 | 100 | 0.23K | 22 | 410 |
| LPC3-2A | 4-8 | 5200 | 3.3 | 99 | 2.25 | 12 | 15 | 17000 | 490 | 70 | 0.17K | 11 | 250 |
| LPC3-3A | 8-12 | 15000 | 7.4 | 220 | 1.31 | 29 | 28 | 37000 | 900 | 110 | 0.26K | 23 | 450 |
| LPC3-4A | 12-16 | 13000 | 7.6 | 250 | 1.95 | 32 | 31 | 39000 | 910 | 120 | 0.29K | 26 | 570 |
| LPC4-1 | 0-4 | 3700 | 3.4 | 99 | 1.43 | 10 | 7.3 | 15000 | 500 | 56 | 0.16K | 9.2 | 170 |
| LPC4-2 | 4-8 | 5100 | 2.9 | 130 | 0.43 | 11 | 6.6 | 18000 | 1400 | 23 | 0.13K | 10 | 85 |
| LPC5-1 | 0-4 | 26000 | 5.9 | 99 | 2.26 | 13 | 13 | 26000 | 310 | 99 | 1.06 | 9.5 | 490 |
| LPC5-2 | 4-8 | 7500 | 12 | 150 | 2.43 | 17 | 12 | 63000 | 1100 | 190 | 1.01 | 17 | 1100 |
| LPC5-3 | 8-12 | 20000 | 56 | 200 | 25 | 47 | 33 | 220000 | 2900 | 1500 | 0.66 | 28 | 6600 |
| LPC5-4 | 12-16 | 5300 | 16 | 79 | 4.49 | 15 | 7.1 | 52000 | 870 | 260 | 0.12K | 9.9 | 1300 |
| LPC5-5 | 16-20 | 6200 | 2.4 | 87 | 0.21 | 5.2 | 3.9 | 7300 | 96 | 20 | 0.15K | 6.7 | 53 |
| LPC5-6 | 20-24 | 5600 | 2.6 | 73 | 0.17 | 4.3 | 3.7 | 7000 | 110 | 16 | 0.15K | 6.8 | 48 |
| **Caddo Lake Sediment Core Data** | | | | | | | | | | | | | |
| CLC1-2 | 0-3 | 6500 | 4.8 | 290 | 0.16 | 22 | 17 | 23000 | 250 | 22 | 0.32K | 24 | 83 |
| CLC1-1 | 3-6 | 5100 | 0.6 | 240 | 0.09 | 11 | 13 | 11000 | 120 | 17 | 0.17K | 11 | 33 |
| CLC2-1 | 0-4 | 5300 | 5.7 | 140 | 0.35 | 9.9 | 5.7 | 23000 | 700 | 19 | 0.18 | 13 | 79 |
| CLC2-2 | 4-8 | 5000 | 1.6 | 160 | 0.42 | 12 | 7.2 | 14000 | 370 | 12 | 0.14K | 7.5 | 30 |
| CLC3-1 | 0-4 | 6500 | 4.7 | 260 | 0.27 | 19 | 13 | 41000 | 740 | 29 | 0.34K | 22 | 110 |
| CLC3-2 | 4-8 | 5400 | 4.6 | 310 | 0.13 | 25 | 15 | 33000 | 660 | 23 | 0.24K | 31 | 83 |
| CLC3-3 | 8-12 | 4100 | 1.3 | 290 | 0.09 | 24 | 19 | 20000 | 450 | 17 | 0.18K | 14 | 62 |
| CL1-1 | 0-4 | 9400 | 0.8 | 27 | 0.04K | 4.1 | 1.8K | 4000 | 67 | 3.6 | 0.13K | 3.4 | 16 |
| CL1-2 | 4-8 | 8600 | 2.6 | 220 | 0.18 | 15 | 5.6 | 19000 | 350 | 16 | 0.19K | 13 | 73 |
| CL1-3 | 8-12 | 7500 | 2.5 | 170 | 0.08 | 14 | 6.3 | 12000 | 300 | 13 | 0.21K | 7.8 | 43 |

*(Continued)*

Note: Units = mg/kg; Depth is in inches; K represents values reported as less than detection the detection limit.

## Table 3 (Concluded)

| Caddo Lake Sediment Core Data | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | Depth | TOC | AS | BA | CD | DR | CU | FE | MN | PB | HG | NI | ZN |
| CL1-4 | 12-16 | 27000 | 3.5 | 230 | 0.18 | 21 | 12 | 16000 | 460 | 22 | 0.23K | 15 | 63 |
| CLC6A-1 | 0-8 | 6200 | 4.1 | 260 | 0.11 | 30 | 18 | 35000 | 770 | 17 | 0.23K | 29 | 76 |
| CLC6A-2 | 8-16 | 8400 | 2.9 | 260 | 0.17 | 22 | 15 | 30000 | 860 | 16 | 0.42 | 26 | 63 |
| CLC6A-3 | 16-24 | 5500 | 6.2 | 340 | 0.23 | 20 | 16 | 39000 | 960 | 28 | 0.27K | 26 | 91 |
| CLC6A-4 | 24-32 | 10000 | 5.1 | 350 | 0.31 | 24 | 19 | 48000 | 1000 | 31 | 0.24K | 29 | 110 |
| CLC6A-5 | 32-40 | 10077 | 10 | 350 | 1.23 | 26 | 44 | 50000 | 1200 | 48 | 0.43K | 35 | 150 |
| CLC6-1 | 0-4 | 4300 | 9.6 | 290 | 0.19 | 17 | 17 | 25000 | 620 | 23 | 0.33K | 29 | 80 |
| CLC6-2 | 4-8 | 12000 | 7.6 | 260 | 0.17 | 22 | 20 | 25000 | 520 | 20 | 0.35 | 34 | 86 |
| CLC6-3 | 8-12 | 12000 | 2.9 | 230 | 0.23 | 18 | 23 | 12000 | 320 | 18 | 0.23K | 19 | 62 |
| CLC6-4 | 12-16 | 18000 | 2.5 | 310 | 0.33 | 27 | 24 | 19000 | 240 | 20 | 0.20K | 24 | 110 |
| CLL1-1 | 0-4 | 16000 | 0.9 | 230 | 0.28 | 11 | 16 | 8000 | 360 | 17 | 0.19K | 9.2 | 34 |
| CLL1-2 | 4-8 | 5800 | 1 | 250 | 0.17 | 12 | 18 | 7400 | 230 | 18 | 0.20K | 9.2 | 32 |
| CLL1-3 | 8-12 | 12000 | 0.6K | 300 | 0.29 | 14 | 26 | 7700 | 230 | 19 | 0.16K | 10 | 18 |
| CLL1-4 | 12-16 | 17000 | 5.6 | 300 | 0.27 | 16 | 17 | 16000 | 430 | 27 | 0.32K | 21 | 93 |

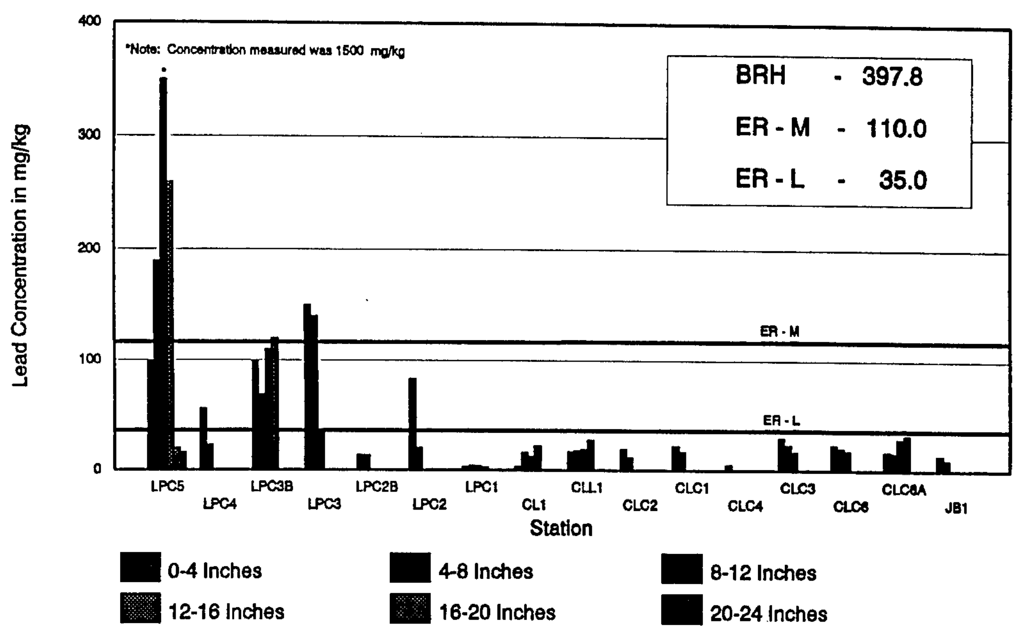


*Figure 2. Sediment core data, lead*

## Table 4
## Elutriate Results

| Metal Data | | AS | CD | CR | CU | PB | HG | NI | AG | ZN | BA | FE | MN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Criteria, µg/L | | 50 | 10 | 50 | 12[1] | 50 | 2 | 160[1] | 50 | 110[1] | 1000 | 300[2] | 50[2] |
| LPC1 | W, µg/L | 3.0K | 0.3K | 13K | 17K | 3.1 | 0.2K | 23K | 9.0K | 54.0 | 73.0 | 1,800 | 190 |
| | S, mg/kg | 0.80 | 0.04 | 3.80 | 2.60 | 3.38 | 0.11 | 2.95 | 1.10 | 11.60 | 32.25 | 5,125 | 67.8 |
| | E, µg/L | 6.6 | 0.35 | 10K | **20.3** | **65.6** | | 12.3 | 1.0K | **162.7** | 374.3 | **38,767** | **1,527** |
| LPC2 | W, µg/L | 3.0K | 0.3K | 13K | 17K | 2.0 | 0.2K | 23K | 9.0K | 40.0 | 66.0 | 1,100 | 130 |
| | S, mg/kg | 5.80 | 0.77 | 16.0 | 11.45 | 525 | 0.18 | 14.5 | 1.5 | 173.0 | 170 | 11,800 | 1,200 |
| | E, µg/L | 29.1 | 0.61 | 22.7 | **72.0** | **300** | | 25.3 | 1.0K | 459.7 | **1,374** | **125,067** | **4,947** |
| LPC3 | W, µg/L | 3.0K | 0.3K | 13K | 31 | 6.9 | 0.5 | 23K | 9K | 100 | 65.0 | 1,400 | 150 |
| | S, mg/kg | 6.08 | 2.06 | 23.25 | 24.25 | 100.0 | 0.00 | 20.50 | 2.30 | 420 | 187.3 | 3,500 | 875 |
| | E, µg/L | 9.2 | 1.3 | 10.0K | **20.3** | **271.3** | | 15.3 | 1.0K | **491** | 432.7 | **32,933** | **1,887** |
| LPC5 | W, µg/L | 3K | 0.3K | 13K | 14.0 | 3.0 | 0.2K | 23K | 9.0K | 54.0 | 70.0 | 1,600 | 220 |
| | S, mg/kg | 15.8 | 5.76 | 16.9 | 12.1 | 347.5 | 0.53 | 12.98 | 1.72 | 1,599 | 114.7 | 62,550 | 897.7 |
| | E, µg/L | 19.5 | 2.2 | 10K | **21.7** | **275** | | 17.7 | 1.0K | **862** | 797 | **47,167** | **1,264** |
| CLC6 | W, µg/L | 3.0K | 0.3K | 13K | 14K | 2.0K | 0.2K | 23K | 9K | 23.0 | 42.0 | 840 | 100 |
| | S, mg/kg | 5.67 | 0.41 | 24.40 | 22.4 | 28.3 | 0.30 | 26.5 | 2.45 | 84.5 | 312.0 | 40400 | 958 |
| | E, µg/L | 6.8 | 0.54 | 12.3 | **33.7** | **58.4** | | 23.7 | 1.0K | **258.3** | **2,170** | **87,367** | **5,997** |
| CLC6A | W, µg/L | 3.0K | 0.3K | 13K | 14K | 2.0K | 0.2K | 23K | 9.0K | 20K | 47.0 | 550 | 100 |
| | S, mg/kg | 6.70 | 0.2 | 0.20 | 19.0 | 28.0 | 0.32 | 29.0 | 2.7 | 98.0 | 272.5 | 20,250 | 425 |
| | E, µg/L | 7.3 | 0.3 | 10K | **16.3** | **32.4** | | 12.7 | 1.0K | 84.7 | **1,011** | **46,467** | **3,690** |

1 Criteria listed are for the protection of chronic freshwater aquatic life.
2 Criteria listed are for the safe consumption of water and fish.
Note:
W = Concentration in water column prior to disturbance.
S = Concentration in sediment prior to disturbance.
E = Concentration in water column after disturbance.

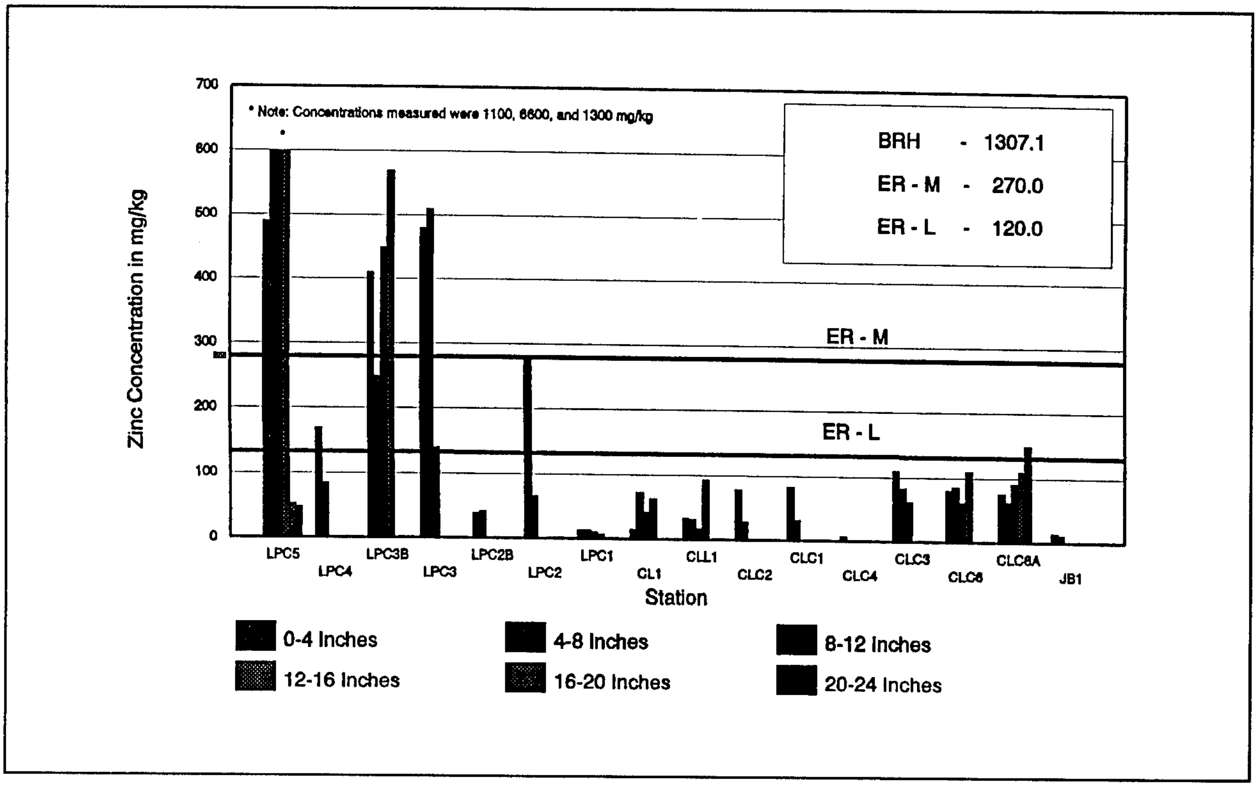


*Figure 3. Sediment core data, zinc*

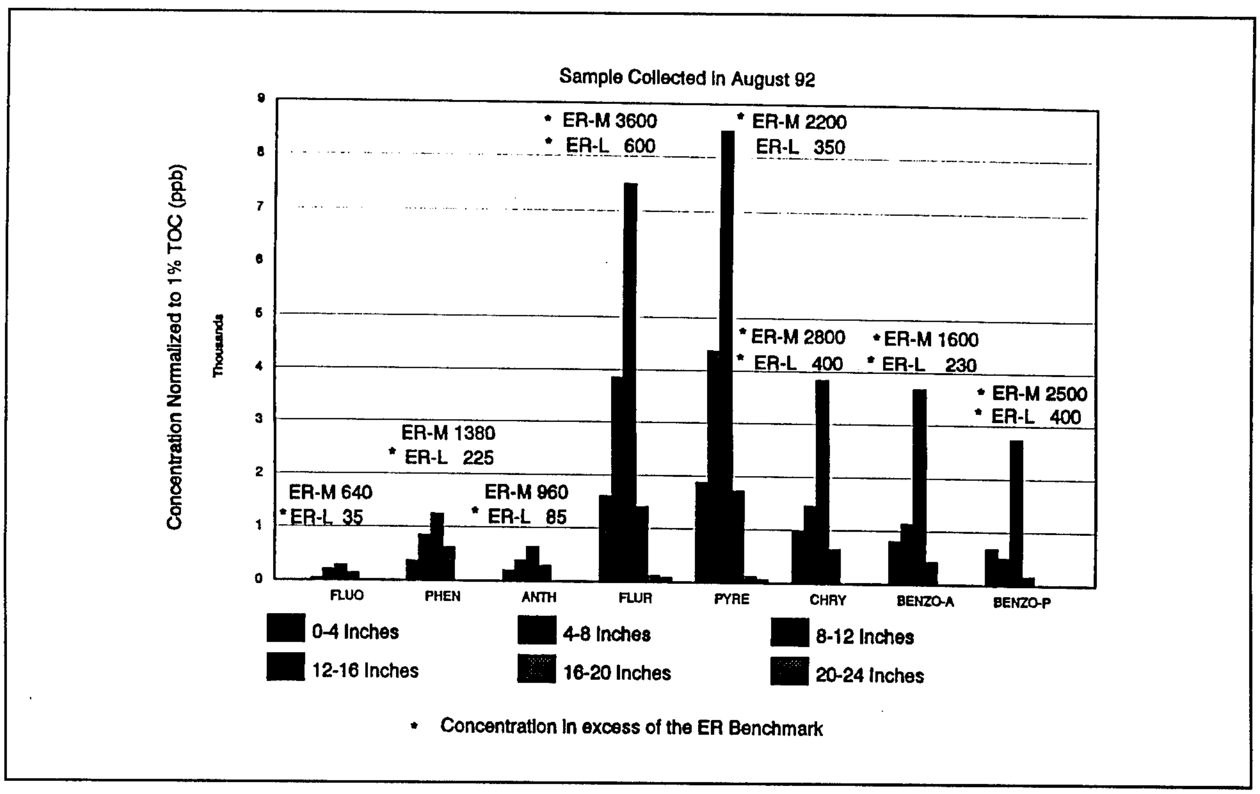


*Figure 4. Lake O'Pines core LP-5 sample*

With various Federal and State agencies and numerous public groups scrutinizing the sampling program, the Tiered Testing methodology provided an efficient, logical, and systematic method for evaluating water and sediment quality on a controversial project in an environmentally sensitive area.

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# Mitigating Saltwater Intrusion through the Hiram M. Chittenden Locks

*by*

*Sherrill L. Mausshardt*[1] *and Glen F. Singleton*[2]

## Introduction

Lake Washington is a large freshwater lake within the Seattle, WA, metropolitan area. It is of significant regional importance for fisheries and recreational activities. The lake is connected to the salt water of Puget Sound by an 8-mile-long ship canal with a lock and dam structure at the downstream end of the canal (Hiram M. Chittenden Locks). The lock and canal provide a navigational link for commercial and recreational vessels between Puget Sound and Lake Washington (Figure 1).

When raising vessels from Puget Sound to the level of Lake Washington, a strong current of salt water flows from the lock chamber into the freshwater system resulting in two conflicting water management issues at the locks: (a) saltwater intrusion control and (b) water conservation. Saltwater intrusion upstream damages the freshwater ecosystem and, if enough salt water entered Lake Washington, could permanently stratify the lake with a layer of salt water at the bottom. This would be socially, politically, and environmentally unacceptable to the region. Controlling saltwater intrusion requires freshwater usage at the locks and conflicts with the need to maintain high lake levels for navigation and recreation. Water conservation, especially during droughts, demands that minimal fresh water be used for lock exchanges and for flushing salt water from the lake. Various methods to prevent salt from reaching the lake have previously been used at the locks. A recent improvement in procedure is discussed in this paper.

## Physical Features

The Hiram M. Chittenden Locks, operated by the U.S. Army Engineer District, Seattle, consist of two separate locks (Figure 2). The smaller lock chamber, which is 46 m long and 9.1 m wide, caters to pleasure craft with up to a 5.0-m draft. The larger lock is 252 m long and 24.3 m wide, accommodating up to 9.1-m draft oceangoing vessels. The larger lock requires about 25 times more lake water per lockage (86,000 $m^3$) than the small lock (3,400 $m^3$) and allows about 25 times more salt water to intrude upstream during a lockage. A middle miter gate allows flexibility in the length of large chamber lockages. The full lock chamber can be used or either the upper or lower chamber depending on the number and size of vessels entering the lock. Lockages occur when gravity-driven flow from the lake fills the lock chamber through two filling culverts and 22 lateral ports along the base of each wall (Figure 2).

The amount of saltwater intrusion from the small lock is insignificant compared with the large lock; therefore, saltwater control measures and physical features are only utilized on the large lock. Several physical structures are present to prevent salt water from propagating upstream with each lake-bound lockage (Figure 2). A saltwater barrier located just upstream of the upper gate blocks the lower, denser salt water from propagating upstream. The barrier is hinged and can be lowered for deep-draft vessels (over 4.4 m draft). When the salt water gets past this barricade, most of it settles into a basin located just upstream of

1 Harris Hydraulics Laboratory, University of Washington, Seattle, WA.
2 U.S. Army Engineer District, Seattle; Seattle, WA.

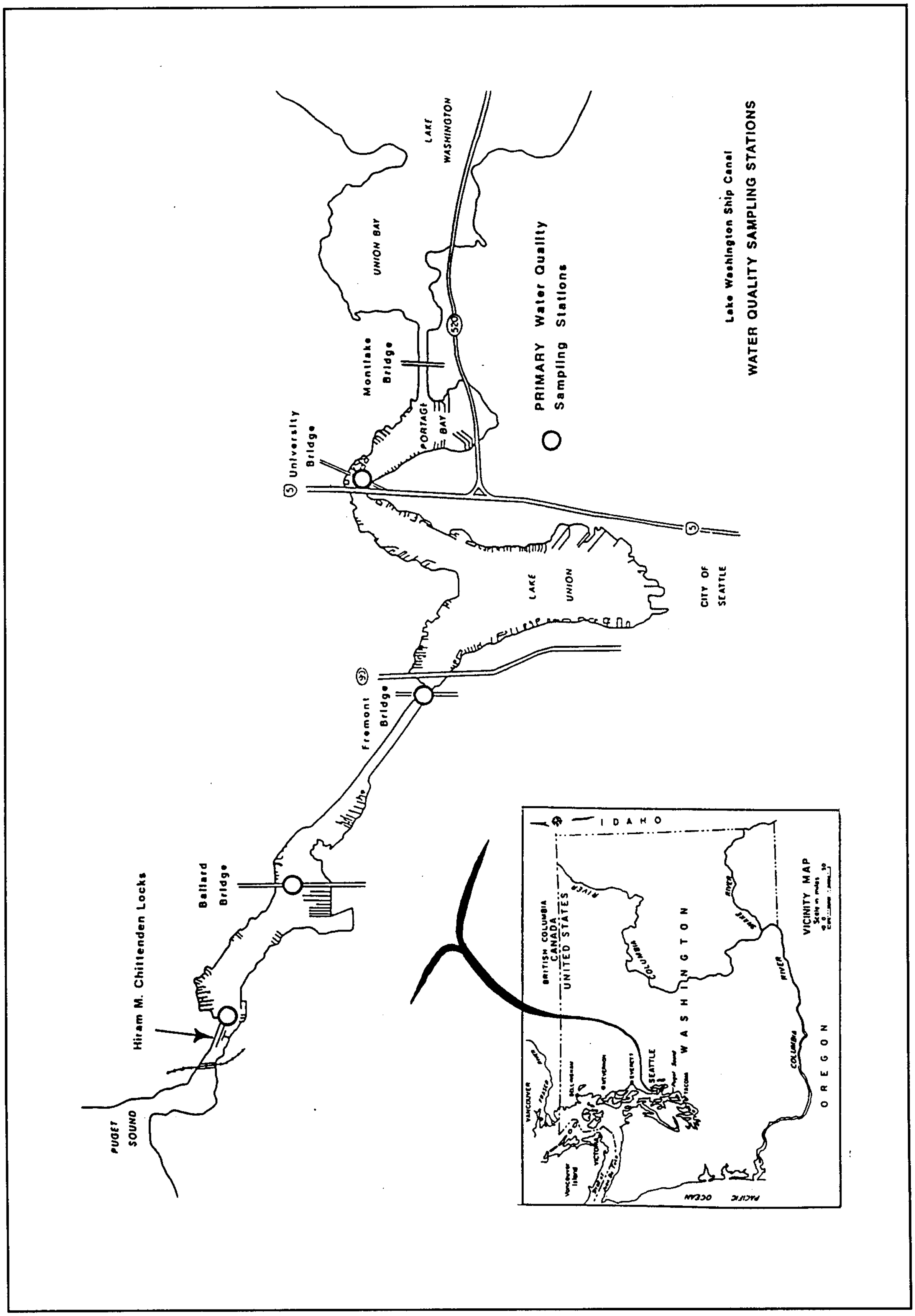


***Figure 1. Vicinity map and water quality sampling stations***

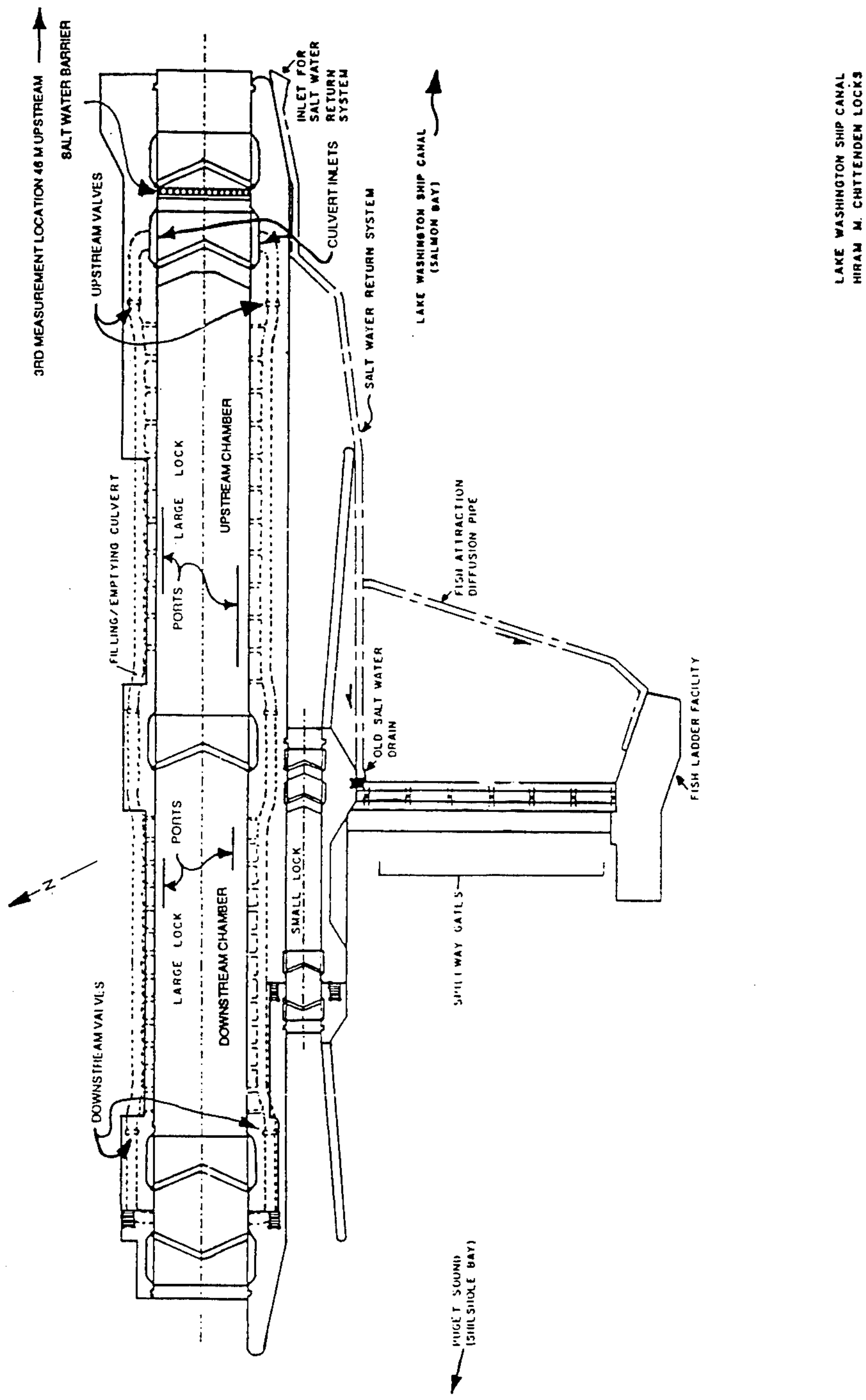


***Figure 2. Hiram M. Chittendem Locks***

the chamber. A saltwater drain removes the denser salt water from this basin by siphoning it back to Puget Sound by gravity.

Saltwater intrusion is generally not a concern in the winter months because of cold-water temperatures in Lake Washington and high outflow rates through the ship canal and the locks. However, during the heavy-use, low-flow summer period, the saltwater drain cannot keep up with the amount of salt water entering the freshwater system. To track the upstream progression of the saltwater wedge, the Seattle District monitors the salinity at five stations on an hourly real-time basis. These stations start at the lock wall and continue up the Lake Washington Ship Canal to the University Bridge (Figure 1) where a Washington State water quality standard of 1.0 part per thousand salinity has been established. Information from these stations is used to make operational decisions regarding lockages and saltwater control measures.

## Experiments

Since the physical features alone do not adequately prevent saltwater intrusion, an additional flushing technique is required to minimize the amount of salt water propagating upstream. Consequently, the Seattle District has implemented a large lock "miniflushing" procedure for summer months. Miniflushing is an operational process that can be temporarily implemented as part of a lockage to minimize saltwater intrusion. Recent field experiments at the locks compared two methods of miniflushing. The first method, where flushing occurs before an upstream lockage (i.e., "prelockage miniflushing") had been used for years. A new method, where flushing happens just after a lockage ("postlockage miniflushing"), was compared with the original. Both miniflushes only occur with upstream lockages. The saltwater barrier was maintained in its upright position during the experiments.

### Prelockage Miniflush

The intent of the prelockage miniflushing method is to flush salt water from inside the lock chamber and immediately upstream of the large lock (because of a previous lockage) back to Puget Sound. Doing so also dilutes the chamber water as the lake water mixes with the brackish chamber water on its way to the sound. The method proceeds as follows: lake-bound crafts are brought into the chamber, and the downstream gate is closed. Salt water is flushed from inside the chamber and upstream of the chamber out to Puget Sound by opening the upstream and downstream valves for the filling culverts (Figure 2). Once the flushing is complete, the downstream culvert valve is closed so that the chamber fills. When the chamber water level reaches the lake level, the upstream culvert valve is closed, and the upstream gate is opened to permit boat passage to the lake.

The experiments were conducted using the lower half of the large lock chamber for a lockage. Salinity readings were taken prior to the flushing to establish initial conditions. The chamber was then flushed for 5 min, and salinity readings were taken at three locations along the lock wall as marked in Figure 2 (i.e., in the lower chamber, at the upstream culvert intake, and 46 m upstream of the culvert intake). The chamber was then flushed for an additional 5 min, and salinity readings were taken at the same three locations.

### Postlockage Miniflush

In postlockage miniflushing, a lockage transpires as it normally would, except flushing occurs after the lock is filled. The lake-bound boats enter the chamber, and the downstream gate is closed. The chamber is raised to lake level by opening the upstream culvert valves while the downstream ones remain closed. Once the chamber water level equals that of the lake, the upstream culvert valves are closed and upper gate is opened. While the upstream gate is opening, the downstream culvert valves are opened. This step flushes salt water from the bottom of the lock chamber into the side-wall ports and out into Puget Sound. It also retards the upstream movement of the saltwater wedge along the bottom of the chamber.

During experiments, the lower chamber was flushed for 5 min before the downstream valves were closed. Salinity readings were taken before filling the lock chamber, once the chamber was full, and then again after the flushing at the same three locations as in the previous test.

## Results

During the prelockage miniflushing experiments, data collected inside the chamber indicated that a minimal amount of dilution occurred during the first 5 min of miniflushing (Figure 3). Only after 10 min of miniflushing was there any appreciable dilution. This was due to the replacement of salt water at the upstream culvert intake (between the saltwater barrier and the upstream miter gate) with fresh water from the lake during the first flushing. The initial and final salinity profiles upstream of the chamber were identical: there was still a considerable amount of brackish water underneath the fresh water. This indicated that the salt water upstream of the chamber was simply replaced with more saltwater from further upstream in the ship canal.

During the postlockage miniflushing experiments, data collected inside the chamber indicated a significant amount of dilution for the 5-min miniflush (Figure 3). Because of the magnitude of the dilution and the vast improvement over the prelockage miniflushing method, no additional durations of postlockage miniflushing were tested. From the data collected at the culvert intake, it was noted that an initial slug of salt water propagates upstream before the valves are fully opened. However, the saltwater slug is small compared with the amount of salt water either flushed into Puget Sound or remaining in the lock chamber. In addition, most of this saltwater slug is stopped by the saltwater barrier when it is in its upright position. The data collected at the upstream location was essentially the same for both miniflushing procedures.

Since the locks are used by migrating salmon, there was concern about the effects of the new miniflushing procedure on fish passage. It was thought that the velocities near the side-wall draining ports would be excessive and cause damage to the downstream migrants. To address this concern, the Seattle District, in conjunction with the U.S. Geological Survey and the University of Washington, investigated the flow pattern inside the lock chamber during a flushing process. An Acoustic Doppler Current Profiler was used to profile the velocity pattern as the boat traversed in a "zigzag" path from one end of the chamber to the other. The velocities near the draining ports were found to be around 1 m/s toward the port, an acceptable velocity for fish passage.

## Conclusions

The field measurements showed that while the prelockage miniflushing drained lake water at the culvert inlets into Puget Sound, the postlockage miniflushing arrested the upstream saltwater propagation and held it at the chamber location. The postlockage miniflushing also significantly diluted the water in the lock chamber. The dilution from 5 min of postlockage miniflushing was far greater than 10 min of prelockage miniflushing and used less fresh water. Clearly, the postlockage miniflushing procedure is an improved means of controlling saltwater intrusion into the ship canal.

As soon as the experimental results were analyzed, a new Standard Operating Procedure was put into effect at the locks that instituted the postlockage miniflushing process. Because the results of the field measurements were so dramatic, the time to miniflush was decreased and stair-stepped according to which chamber would be used. For example, if the full lock chamber is used, then the miniflushing lasts for 5 min. Whereas, if just the upper or lower chamber is used, then the miniflushing lasts for 3 and 2 min, respectively. Decisions regarding when to miniflush are based on water supply forecasts for Lake Washington and on the real-time salinity data collected from the five automated monitoring stations in the ship canal.

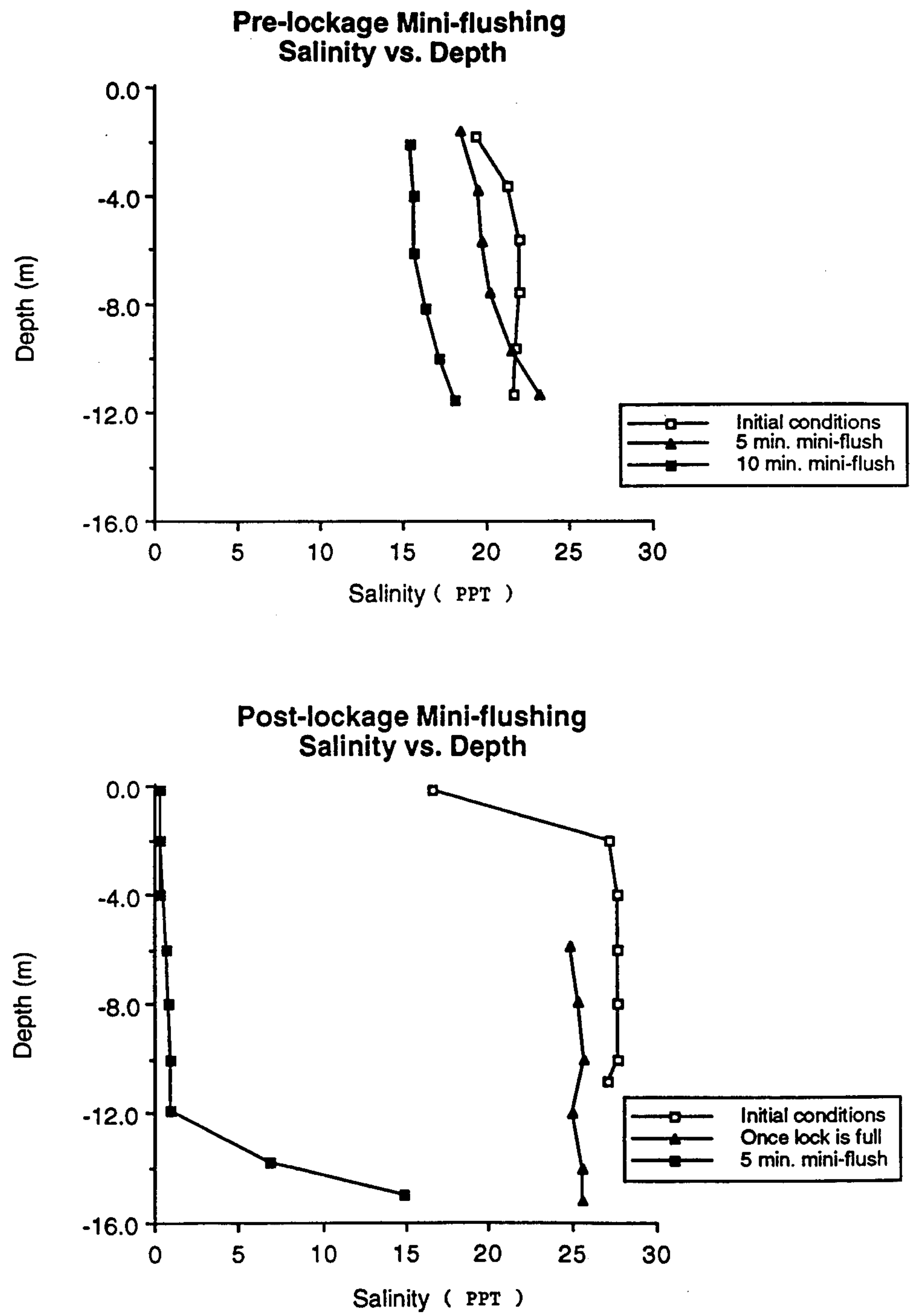


*Figure 3. Miniflushing experimental results*

Perhaps the most dramatic effect of the new process can be seen by noting the change in upstream levels of salinity for July and August of 1991 and 1992 (Figures 4 and 5). The figures show the hourly salinity data collected on the south lock wall of the large locks and below Ballard Bridge in the Lake Washington Ship Canal. In June and early July, there were approximately the same salinity levels at the large lock location for both years. Tests began on 10 July 1992, and the new method was instituted on 17 July. Once the new postlockage miniflushing technique was implemented, the salinity level dropped significantly. Note that at the Ballard location, the salinity is zero for much of the summer of 1992 (despite drought conditions in the Pacific Northwest, which required implementation of water conservation measures). In fact, the salinity only increased in August after the miniflushing was stopped temporarily on 6 August and decreased again as soon as it was reinstated on 17 August.

Clearly, the new miniflushing technique provides water managers with a valuable means for controlling saltwater buildup in the lake system. Also, the new miniflushing technique uses less fresh water, resulting in higher lake levels for recreation and navigation. This was especially important in 1992 when the Pacific Northwest was experiencing drought conditions. Historically, drought conditions have caused water management and water quality conflicts resulting in sacrificing lake levels (i.e., drawing Lake Washington down below its authorized minimum elevation) to prevent intrusion of salt water into Lake Washington. The new postlockage miniflushing technique proved to be a major factor in maintaining adequate lake levels, while still preventing salt water from reaching Lake Washington.

## Acknowledgment

This work was partially funded through University of Washington Professor Harry Yeh by Washington Sea Grant.

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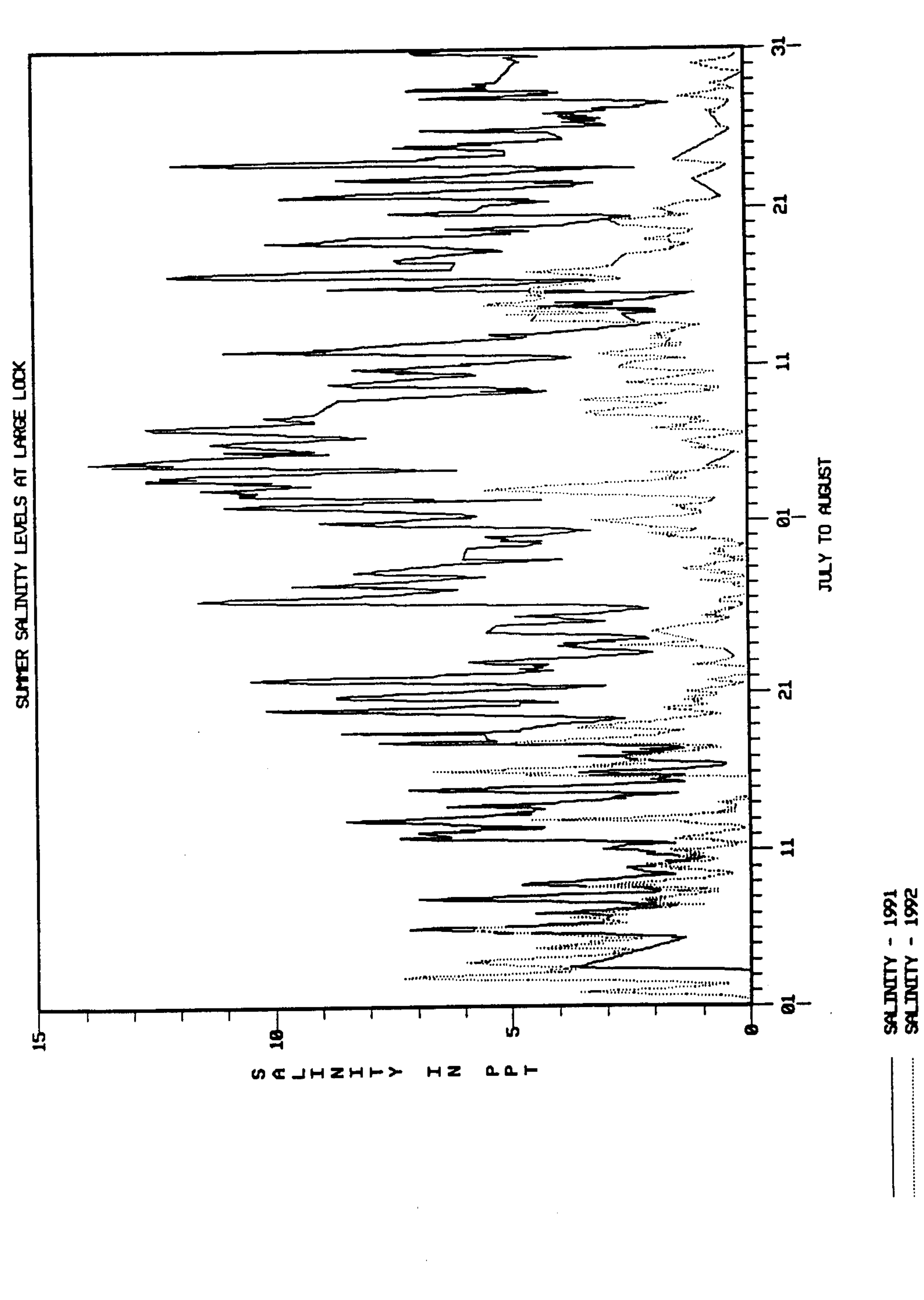


*Figure 4. Summer salinity levels at large locks*

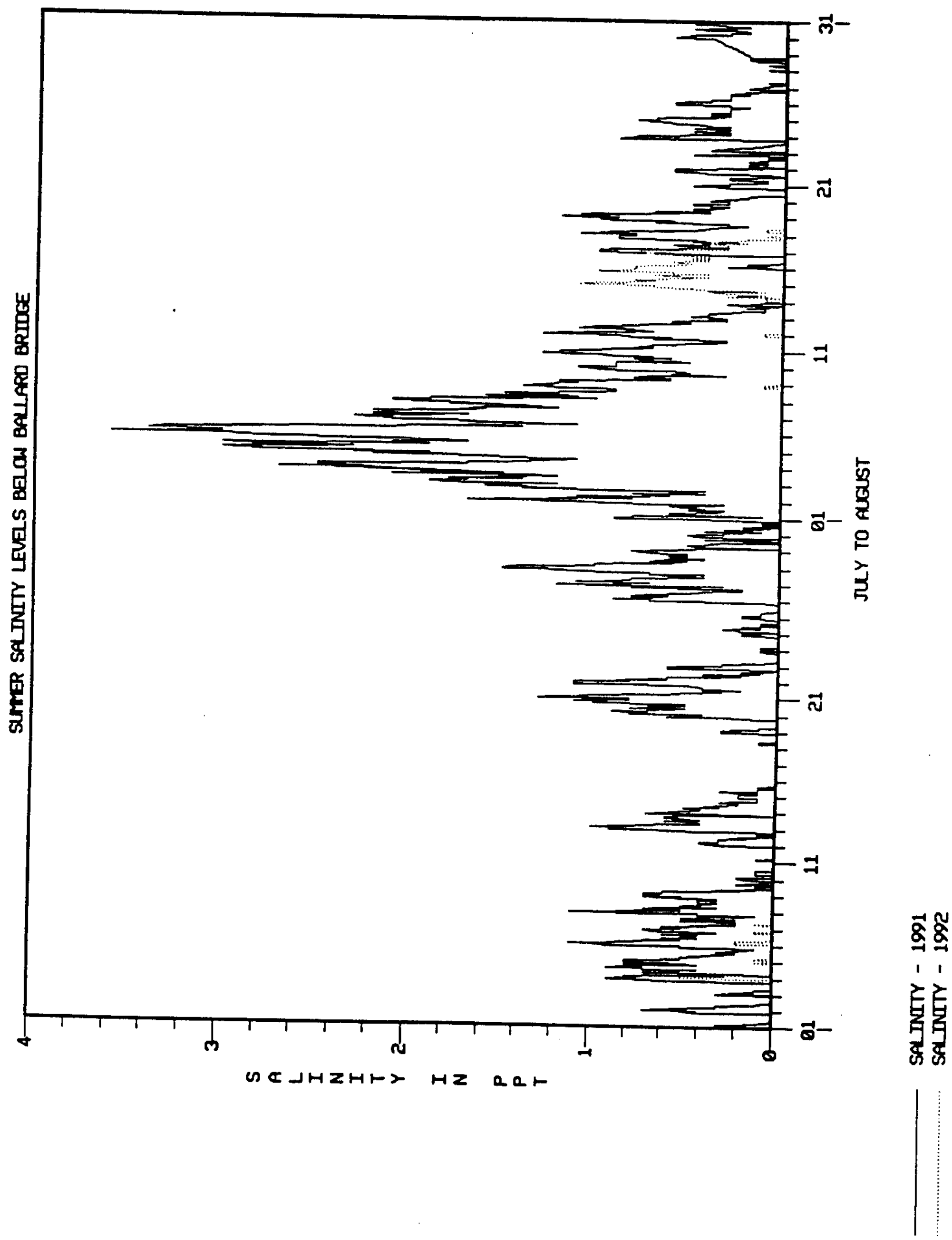


*Figure 5. Summer salinity levels below Ballard Bridge*

# Assessment of Water Quality Impacts to Lake Pontchartrain, Louisiana, by the Bonnet Carre Freshwater Diversion Project

*by*
*Marvin A. Drake*[1]

## Introduction

Lake Pontchartrain, a shallow estuarine embayment bordering the New Orleans metropolitan area, and adjacent wetlands and water bodies support abundant populations of fish and shellfish (Figure 1). Natural subsidence and erosion, however, augmented by the effects of levee and channel construction, have promoted saltwater intrusion, losses of wetlands, and reductions in fisheries. The Bonnet Carre Freshwater Diversion (FWD) Project is designed to discharge up to 30,000 cfs into the lake from the Mississippi River to reduce salinity levels in Lake Borgne and Mississippi Sound. The project would greatly enhance oyster productivity, significantly improve fish and wildlife productivity, and reduce wetlands losses.

Recently expanded public awareness of Lake Pontchartrain's value as a natural resource and of its potential for swimming and other recreational activities with the implementation of urban storm-water control and treatment measures has raised new concerns about whether the project's adverse water quality impacts might exceed its environmental benefits. These and other expressed concerns led to the preparation of an Environmental Assessment (EA) U.S. Army Corps of Engineers (USACE 1993a) to complement and update the 1984 Environmental Impact Statement (EIS) (USACE 1984a). A Water Quality Assessment (WQA) (USACE 1993b) was prepared as an Appendix to the EA to assess the water quality impacts of the Bonnet Carre FWD Project. The WQA was based heavily on the study of monthly water quality data from river and lake sampling stations monitored by the Louisiana Department of Environmental Quality (LDEQ) and the U.S. Geological Survey (USGS) and the intensively monitored Bonnet Carre Spillway floodwater diversion event of April and May 1979. The Water Quality Appendix to the Bonnet Carre FWD Structure Feasibility Report (USACE 1984b) and the EIS were reviewed in light of new information that had become available since 1984.

LDEQ has documented evidences of water quality and trends in the lower Mississippi River since 1982 through various monitoring and surveillance activities. Their implementation of progressively restrictive discharge requirements has resulted in substantially reduced pollutant loads from industrial and municipal dischargers in the Baton Rouge to New Orleans reach of the river. Fecal coliform bacteria levels in the river have dropped dramatically since 1988 when disinfection of municipal wastewater became a requirement.

Studies conducted by LDEQ, USGS, and the U.S. Environmental Protection Agency (USEPA) and other agencies and institutions during the past decade have significantly advanced the knowledge and understanding of water, sediment and fish tissue quality and trends of the Mississippi River in Louisiana and elsewhere in the basin. A recent report (USEPA 1992) documents the potential bioavailability of trace metals in water and sediments. The WQA also addressed a future "clean lake" condition that would exist were urban storm-water runoff from Orleans and

[1] U.S. Army Engineer District, New Orleans; New Orleans, LA.

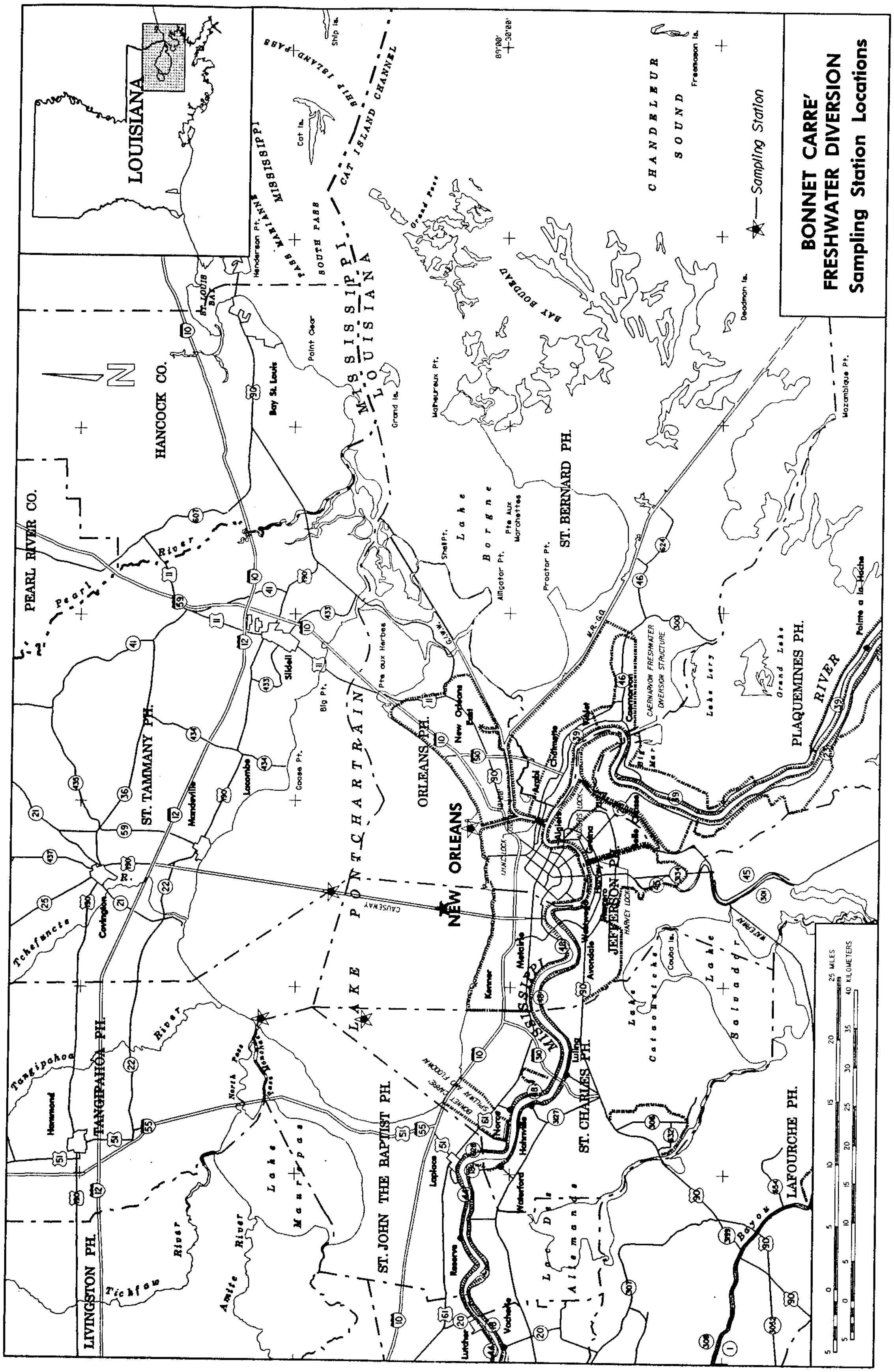
BONNET CARRE'
FRESHWATER DIVERSION
Sampling Station Locations
Sampling Station
LOUISIANA
MISSISSIPPI
LOUISIANA
HANCOCK CO.
PEARL RIVER CO.
ST. TAMMANY PH.
TANGIPAHOA PH.
LIVINGSTON PH.
ST. JOHN THE BAPTIST PH.
ST. CHARLES PH.
JEFFERSON PH.
ORLEANS PH.
ST. BERNARD PH.
PLAQUEMINES PH.
LAFOURCHE PH.
LAKE PONTCHARTRAIN
Lake Borgne
Lake Maurepas
Lake Salvador
Lake Cataouatche
NEW ORLEANS
CHANDELEUR SOUND
CAT ISLAND CHANNEL
MISSISSIPPI RIVER
Pearl River
Tickfaw River
Amite River
Tangipahoa River
Tchefuncte River
Covington
Mandeville
Slidell
Hammond
Kenner
Metairie
Chalmette
CAUSEWAY
BONNET CARRE SPILLWAY
CAERNARVON FRESHWATER DIVERSION STRUCTURE
25 MILES
40 KILOMETERS

*Figure 1*

Jefferson parishes to be controlled and treated sufficiently for the southern lakeshore to meet the State of Louisiana's primary contact recreation bacterial standard and be declared safe for swimming.

Empirical relationships of Lake Pontchartrain water quality responses to pollutant loadings in diversion flows were derived for the constituents considered to be potentially problematic, including turbidity, nutrients and fecal coliform bacteria. Salinity was also assessed quantitatively as a significantly affected constituent. The results of the assessments of impacts of the potentially problematic constituents are described. An independent study of nutrient impacts is discussed in conjunction with the nitrate assessment. The assessments of organic chemicals, trace metals, and temperature are also described to indicate their minimal impacts.

## River and Lake Water Quality and Trends

### Mississippi River

Lower Mississippi River water quality is seasonally variable for most constituents in response to river discharge, suspended sediment concentration, temperature, and other factors. Point source inflows occur at numerous industrial and municipal wastewater locations in the Baton Rouge - New Orleans reach, and nonpoint sources are minimal since the reach is leveed and no tributaries enter from the alluvial floodplain.

Suspended solids and turbidity levels are closely related to river discharge and are greatest in the winter and spring. Although high compared with most major rivers, they have been decreasing with time because of reduced soil erosion in the basin, sediment trapping by reservoirs, and channel stabilization works in the river.

The river is consistently high in dissolved oxygen (DO), maintaining a ratio of three or more to biochemical oxygen demand (BOD). Nutrients are abundant, with nitrate nitrogen averaging about 1.2 mg/L. Nitrate levels are somewhat higher in the spring, but phosphorus has no distinct seasonal pattern. Temperatures average several degrees cooler than Lake Pontchartrain and other south Louisiana water bodies because most of the river basin lies in midcontinent latitudes and the coastal water bodies are much shallower.

Bacterial pathogens are highly variable throughout the year and are most reflective of municipal wastewater discharges. Fecal coliform colony counts of 100 to 500/100 ml had been commonly measured at the Luling sampling station (USGS) before 1988, with occasional counts of 800/100 ml or more. The required disinfection of municipal discharges since 1988 has substantially reduced river fecal coliform levels to the extent that the reach containing the diversion site now supports primary contact recreation.

Most pesticides and other synthetic organic compounds are detectable, if at all, at very low concentrations. Pesticide levels have been decreasing with time because of prohibitions on the most toxic and persistent compounds, and improved industrial wastewater treatment methods have significantly reduced the concentrations of most of the other organic chemicals. Public concern about toxic chemicals in drinking water supplies in the early 1980s resulted in the establishment by LDEQ of the Early Warning Organic Compound Detection System (EWOCDS) that alerts water treatment plants and other users when high levels of certain compounds are detected, usually because of spills (Cormier et al. 1992). Trace metal concentrations, though occasionally above their aquatic life criteria, have likewise demonstrated significant decreasing trends primarily because of the implementation of improved wastewater-treatment technology.

### Lake Pontchartrain

Lake Pontchartrain water quality constituents vary seasonally in response to tributary discharges and other point and nonpoint discharges including urban and agricultural

runoff, temperature, salinity, and wind forcing. Water quality perturbations occur more often near tributary mouths, urban storm water and wastewater outfalls, and the Inner Harbor Navigation Canal (IHNC) entrance than within the main body of the lake.

Nearshore turbidity is relatively high during winter and spring runoff periods, but wind wave turbulence intermittently generates elevated turbidity levels by resuspending bottom sediments except in the lake's deeper eastern waters. Dissolved oxygen is usually sufficient for aquatic life, but severe oxygen deficits have occurred in the southeastern lake extending outward from the IHNC entrance. Saltwater intrusion from the Mississippi River-Gulf Outlet (MRGO) deep-draft channel, in the presence of high temperatures, slow circulation, and low basin runoff, has induced widespread density stratification and resultant deoxygenation of bottom waters in some years. Mid-Lake salinity varies between seasonal medians of 4.4 parts per thousand (ppt) in the fall and 2.2 ppt in the spring. At the lake's western end, the corresponding medians are 1.7 and 0.9 ppt at Pass Manchac.

Nitrogen and phosphorus concentrations are normally much larger near tributary mouths and other nutrient sources including Orleans and Jefferson parishes outfall canals than in the interior of the lake. In comparison with temperate freshwater lakes, Lake Pontchartrain is classified as eutrophic on the basis of its nutrient loading and concentrations, but its relatively stable oxygen regime, its natural wind-driven turbulence, and its reduced light penetration do not support a eutrophic classification (Bryan et al. 1994). Nitrogen has been identified as the growth-limiting nutrient for phytoplankton in the summer and fall (Dow and Turner 1980).

Lake fecal coliform levels are ordinarily highest near the south-shore pumped outfalls, tributary mouths, and domestic wastewater sources along the developed north shore. Although south-shore fecal coliform levels have become lower since 1988 because of Orleans Parish (New Orleans) sewerage improvements and the completion of a regional sewage treatment plant in Jefferson Parish, 10-percent exceedence levels have remained well above the 400/100 ml criterion for primary contact recreation within 1/4 mile of the outfalls.

Synthetic organic compounds are rarely detected in the lake waters. Bottom sediment samples in the southern portion of the lake in 1982 and 1983 revealed much lower levels of polychlorinated biphenyls (PCBs), DDT, and other chlorinated hydrocarbons near the urbanized shoreline than had been measured in other similarly developed estuarine zones around the nation (Schurtz and St. Pe 1984). Metals were not detected above natural background levels in sediment samples taken 4 to 6 miles from the south shore.

## Descriptions of Impact Assessments

### Analytical Methods

This section describes the data sets, rationale, and methods employed in the quantitative assessments of Lake Pontchartrain water quality impacts for turbidity, nitrate nitrogen, total phosphorus, and fecal coliforms. Monthly median and worse case (50th and 10th percentile) values were compiled for each constituent in the Mississippi River for the 1979-1992 record period except for fecal coliforms, which were limited to the referenced 1988-1992 period because of the revised permit restrictions on municipal wastewater discharges. The longer fecal coliform database was employed, however, to obtain better estimates of the relative proportions of the monthly 10th percentile values. For each constituent, the 10th percentile values were smoothed by weighting each month with the two adjacent months to compensate for the influence of extreme values (outliers). Monthly median constituent values were compiled for the lake water quality stations nearest the diversion outfall site: Mid-Lake; IHNC entrance; South Causeway; and Pass Manchac (Figure 1).

Table 1 shows the schedule of computed monthly project design Bonnet Carre FWD discharges (USACE 1984c) that would be required to attain the monthly target salinity levels for optimal oyster production during a typical (median) salinity year in the Bay Boudreau oyster reef area. It is noted that 81 percent of the annual diversion volume would occur in March, April, May, and June, and that 34 percent of the total would be in April. Primary consideration was therefore focused on Lake Pontchartrain water quality effects in March through July, with special attention to April and May.

These flows were multiplied by the respective median and worse case river water quality constituent levels to compute the hypothetical monthly volume fluxes (loading rates) that would prevail during a typical salinity year. The fluxes were applied in turn to the derived mathematical relationships of the April and May 1979 Bonnet Carre Spillway diversion volume fluxes to the water quality constituent level changes that occurred at lake sampling stations. Spillway discharge and Spillway and lake water quality were measured 5 to 7 days per week throughout and well beyond the diversion period (USGS 1980).

Empirical least squares regression equations were derived that reasonably explained lagged water quality responses to the diversion fluxes for most constituent-station combinations, particularly during and following the gradual recession of Spillway flows from sustained levels of 175,000 cfs or more to minimal values. Viable relationships could not be derived for most of the combinations involving the Pass Manchac station, indicating comparatively little diversion influence at that location. The other stations for which empirical relationships were derived were Mid-Lake, IHNC, and a temporary site about 9 miles from the Spillway outfall (Figure 1). A similar regression approach had been employed to model the salinity reduction effects of the 1979 Spillway diversion event in the Feasibility Study for the FWD Project (USACE 1984a). These derived relationships were the primary basis for most of the quantitative salinity impact assessments described in this section.

Regarding the urbanized south shore, the most heavily utilized area of the lake, the adaptation of the 1979 diversion event as a model for assessing the advective and mixing tendencies of FWD plumes is considered to present a conservative approach for the impact assessments. The dominant eastward component of the 1979 diversion plume produced more dramatic and sustained water quality changes at the 23-mile distant IHNC entrance than at the station located 9 miles to the northeast of the outfall. It can be reasonably presumed that the much smaller momentum of FWD plumes would make them succumb more rapidly to prevailing lake current dynamics, according to the observed drift patterns in 1978 and 1979 and the documented influence of seasonally prevailing winds (Gael 1980). This should cause them to favor a somewhat more northeasterly course during the spring, veering gradually farther from the south shore into deeper water.

A different analytical approach was taken for assessing the fecal coliform effects of freshwater diversion. Fecal coliforms and other bacteria have been observed to decrease in population (die-off) at predictable rates in

**Table 1**
**Project Design Diversion Flows Required for Optimal Salinity in Bay Boudreau, 1,000 cfs**

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow | --- | --- | 10.8 | 30.0 | 16.7 | 14.6 | 3.2 | 2.6 | 2.0 | 5.5 | 3.2 | --- |

water bodies (Jorgensen 1979). These rates can be expressed by a first-order equation:

$$C = C_0 e^{-KT}$$

where

$C$ = bacterial concentration at time T, #/100 ml

$C_0$ = initial concentration, #/100 ml

$K$ = decay (die-off) coefficient

$T$ = elapsed time, days

In natural waters, K has been found to range from 0.05 to 4.0 for fecal coliforms. The U.S. Army Engineer District, New Orleans, experimentally determined a K value of 0.7 for Mississippi River water in 1984.

Travel times for diversion flows to reach selected locations in Lake Pontchartrain were estimated by application of a two-dimensional numerical model, RMA-2, a component of the TABS-MD modeling system (Thomas and McAnally 1990). It was determined that for a sustained diversion flow of 30,000 cfs, the average velocity vector of the diversion plume would be 0.1 ft per sec (fps), or about 3 cm per sec. Using this velocity, elapsed travel times of about 2 to 14 days were calculated for selected sites ranging from Frenier Beach, 3 miles from the outfall on the southwest shoreline, to the IHNC entrance at a distance of 23 miles east of the outfall.

## Summary of Turbidity Impacts

The quantitative analysis of project design flow impacts revealed a pattern of moderate turbidity increases in the vicinity of the IHNC entrance and presumably for some distance beyond along the south shore. Comparisons of the predicted median and worse case spring maximum turbidity increases at any station of 9 and 14 Nephelometric Turbidity Units (NTU) over ambient lake levels to the LDEQ standard of 50 NTU for Lake Pontchartrain showed that it would be unlikely to be exceeded in populated nearshore areas (Jefferson Parish). It was further concluded that the seasonal normal countercurrent to the west along the inner shoreline of the lake would tend to reduce nearshore impacts. A projected future "clean lake" scenario for the south shore, wherein its overall water quality would approach that of the lake's interior, should have little effect on the resultant diversion-induced turbidity levels because most of the solids in urban runoff discharges tend to settle quickly to the bottom once beyond the turbulent mixing zones near the pumping station outfalls.

## Summary of Nitrate Impacts

Nitrate nitrogen is abundant in the river, with commonly occurring levels of 1 to 2 mg/L. Typical Lake Pontchartrain nitrate levels are comparatively low, averaging about 0.1 mg/L near shorelines and about 0.05 mg/L or less in open-water areas. Although nitrogen is the major growth-limiting nutrient in the lake, inorganic nitrogen (nitrate) levels are suppressed by turbidity and wind action, which promotes the scavenging of inorganic matter by bottom sediments.

In the 1979 diversion event, nitrate+nitrite[1] levels at the IHNC entrance station responded rapidly to the influx from the river, rising from a prediversion level of 0.08 to 1.8 mg/L (nearly as high as within the Spillway) within 3 weeks from the beginning of the diversion period. As diversion flows receded from sustained levels of 175,000 cfs or more to virtually zero by late May, the IHNC station's nitrate +nitrite level declined to about 0.03 mg/L by mid-June. The predicted median and worse case maximum nitrate+nitrite increases at the IHNC entrance for project design conditions were 0.77 and 0.97 mg/L and were 0.41 and 0.57 mg/L at the temporary 9-mile distant station. The corresponding predicted maximum increases at Mid-Lake were 0.08 and 0.11 mg/L.

[1] The nitrite fraction of nitrate+nitrite averaged about 3 percent in the Spillway and lake samples.

As noted above, the derived regression relationships reflect the 1979 diversion plume's decidedly easterly course. A single-layered finite element model, CAFE-1 (Wang and Connor 1975), was applied to Lake Pontchartrain by Gael (1980). The study concluded that wind forcing is the most important single driving mechanism on water movements. Nearshore water moved with the wind and counter flows developed offshore. Very large sustained flows of 100,000 cfs or more from the Bonnet Carre outfall site effectively suppressed the longshore wind-driven currents, indicating that the 1979 diversion would have established such a circulation pattern within a reasonable time period. The extent to which a freshwater diversion rate of 30,000 cfs or less would overcome a wind-dominated circulation pattern and mimic the easterly flow path of a Spillway diversion has not been rigorously determined. It is nevertheless surmised that its dominant path would likely be oriented relatively more toward the northeast and it should impact south-shore areas to a somewhat lesser degree than predicted by the empirical relationships.

Although the 1979 diversion event delivered an estimated load of 43 million pounds of nitrate+nitrite to Lake Pontchartrain, no eutrophying tendencies were reported in the most affected south-shore area. The presence of elevated turbidity was undoubtedly a major factor, but other factors and processes might also have been important. During a year of project design diversion rates, the total load of nitrates +nitrites to the lake, assuming typical river concentrations, would be about 24 million pounds, or about 56 percent of the 1979 diversion load. It appears that this smaller loading of inorganic nitrogen, occurring over a longer time span, would be more easily assimilated and recycled with relatively little risk of overenrichment or eutrophication. Overall lake productivity would thus appear to be significantly enhanced by freshwater diversions without incurring overenrichment and its attendant problems. Although the FWD project was not designed specifically to improve the water quality and ecology of Lake Pontchartrain, its input of significant amounts of Mississippi River water into and through the lake during moderate-to-high salinity years would not only compensate for tributary runoff deficits but should also effectively restore a major natural source of nutrients that had been denied the lake since the modern flood protection levee system was built.

The New Orleans District commissioned an independent study to address the question of nutrient impacts to Lake Pontchartrain by the Bonnet Carre FWD project. A draft progress report (Bryan et al. 1994) commented on two important indicators of trophic state of a water body that do not support a eutrophic classification for the lake. The highest recorded dissolved oxygen values in the lake are only slightly above saturation, whereas eutrophic lakes typically show large diurnal swings of DO to far above saturation levels. Turbulence, lack of stratification, and reduced light penetration may each contribute to the stable DO ranges in spite of the large nutrient influxes that occasionally occur. A second indicator that fails to support a eutrophic classification for the lake is the reported loss of grass beds and related fishery habitats. The report suggested that increases in lake nutrients may lead to the recovery of some of the habitats.

The report further noted the documented tendency for low nitrogen to phosphorus ratios to trigger the onset of nitrogen-fixing blue-green algae in nature because of their competitive advantage over other phytoplankton forms in balancing their N:P requirements. Preliminary analyses indicated that the present N:P ratio in Lake Pontchartrain is about 10, or well above the ratio at which blue-greens would lose their advantage. If further assessments of the composition and abundance of phytoplankton relative to possible differences in N:P ratios follow the observed pattern of developments with eutrophication of freshwater lakes, blue-green algae should be fewer where N:P ratios exceed an empirically determined threshold. Since it is believed that threshold is presently exceeded throughout the system, the tendency of freshwater diversion nutrient inputs to further increase N:P

ratios would effect no detectable increase in the proportion of blue-greens. Should this be the case, there would be no increased production of noxious forms, i.e., algal blooms, and thus no significant adverse water quality effects of diversion.

The remaining tasks of the nutrient study are as follows:

- Completion of the assessments of algal cell counts in phytoplankton samples collected by USGS.
- Overlaying the phytoplankton and nutrient loading data (USGS) on a two-dimensional physically based model of the lake.
- Modeling various diversion and hydrometeorologic condition scenarios to examine the effects of the major nutrient sources on eutrophication tendencies in the lake.

## Summary of Phosphorus Impacts

The median phosphorus level in the Mississippi River is 0.24 mg/L, and the 10th percentile concentration is 0.50 mg/L. Typical Lake Pontchartrain levels are about 0.10 mg/L near tributary mouths, probably somewhat higher near urban outfalls, and are about 0.05 mg/L in open water. Phytoplankton growth is believed to be phosphorus limited in the late spring, but runoff and wind forcing are often the dominant factors in primary productivity (Dow and Turner 1980).

The quantitative assessment of FWD phosphorus loading to the lake yielded moderately increased concentrations that were well within the commonly measured ranges at each station. The maximum predicted median and worse case increases were 0.06 and 0.07 mg/L at the IHNC entrance. These changes are considered too small to trigger eutrophication or other undesirable effects. The influxes of phosphorus should have a net positive effect on lake productivity and would tend to compensate for projected future phosphorus deficits from south-shore drainage areas under the referenced "clean lake" scenario.

## Summary of Fecal Coliform Impacts

Fecal coliforms are the most commonly employed indicator organisms for the bacterial pathogens that exist in fecal material from humans and other warmblooded animals. LDEQ uses fecal coliform data to determine the suitability of water bodies for primary contact recreation, shellfish harvesting, and other designated water-use categories. Mississippi River diversions to Lake Pontchartrain have been viewed negatively by the general public because of the perceived threat of renewed bacterial contamination in nearshore areas that could become swimmable with the attainment of desired future control and treatment measures for urban runoff water that is frequently contaminated with untreated sewage.

The application of the die-off rate of 0.7 (70 percent per day) in river water to the maximum project design diversion flow of 30,000 cfs in April for typical and worse case river conditions yielded predicted resultant fecal coliform levels of 35 and 77/100 ml, respectively, at Frenier Beach, about 3 miles north of the diversion outfall, and corresponding levels of 6 and 13/100 ml at the St. Charles and Jefferson parish boundary, about 7 miles east of the outfall. These values would apply if complete displacement of the ambient lake water occurred, an increasingly unlikely condition with increased distance from the outfall and smaller diversion rates.

Although no measurements of the die-off coefficient for Lake Pontchartrain water are available, it should be higher than for river water because of the natural disinfecting property of saline water. The tendency for the diversion waters to gradually mix with and disperse among lake waters as their initial energy dissipates over time and space would further reduce any predicted fecal coliform increases. The review of fecal coliform measurements at lake sampling stations with respect to the 1979 Bonnet Carre Spillway

influx indicated that other than minimal differences should not be expected for FWD project design discharge conditions.

In summary, any increases in fecal coliform levels in Lake Pontchartrain resulting from diversions should be small and well within the commonly experienced ranges of variation except near the outfall location. The diversions should in fact help to improve nearshore water quality in urbanized Jefferson and Orleans parishes, especially near the drainage outfalls, by diluting and dispersing the discharged runoff waters over larger areas, thereby reducing pollutant concentrations, including fecal coliform levels.

## Summary of Salinity Impacts

The diversion of Mississippi River water into Lake Pontchartrain at project design rates would completely or virtually freshen some nearshore areas. The average spring salinity at the IHNC entrance would be lowered by more than 50 percent. During the spring, the average salinity throughout the lake would be reduced below the average level prior to the completion of the deep-draft MRGO navigation channel in 1963, which effected a lakewide average increase in salinity of about 1.5 ppt. During the summer months, project diversions would reduce average eastern lake salinity by about 20 percent. The southern shoreline areas between the outfall and Little Woods (6 miles beyond the IHNC) would experience freshening beyond that which would occur, on the average, in 9 of 10 years under the existing condition. These locations should generally benefit from the flushing action and oxygenization that the river waters would impart in the spring, and also during the summer when the diversion flows would partially compensate for the naturally slower lake circulation and higher temperatures that contribute to density stratification problems and possibly severe dissolved oxygen deficits near the IHNC entrance.

Potential salinity stress to cypress swamps along the western margin of the lake would be reduced (USACE 1993a,b). During the spring and early summer, both the abundance and diversity of freshwater fish species should increase, but estuarine and marine species would be displaced eastward toward Lake Borgne and Mississippi Sound. Optimal salinity levels should prevail for oysters in the Bay Boudreau target area.

## Toxic Organic Chemicals Assessment

Hundreds of synthetic organic compounds have been detected at various times in the lower Mississippi River, but detection of those known to be toxic to aquatic life or threatening to human health have become increasingly rare in recent years. The EWOCDS program, established in 1986 by LDEQ to warn river water users of chemical discharges or spills, now includes daily monitoring at eight sites between Baton Rouge and St. Bernard Parish, below New Orleans. Volatile organic compounds (VOCs) have been detected in about 21 percent of the samples, and drinking water criteria have been exceeded in about 3 percent of the analyses. Since January 1991, LDEQ has analyzed for 87 organic priority pollutants in the river at St. Francisville and Pointe a la Hache, upriver and downriver of the FWD site. During the first 22 months of the program, detections were recorded in only 0.5 percent of the analyses, and no aquatic life criteria were violated. Since 1988, LDEQ wastewater discharge permits have been water quality based, requiring compliance with human health and aquatic life criteria under the Clean Water Act.

Other active monitoring projects include the Mississippi River Toxics Inventory, in which LDEQ analyzes the edible portions of selected commercial and recreational fish and shellfish for herbicides, pesticides, and priority pollutants. No U.S. Food and Drug Administration (USFDA) Alert Levels for human consumption were exceeded in any of the composite samples, and no fish consumption advisories have been warranted. Since 1969, the U.S. Fish and Wildlife Service (USFWS) has

been analyzing fish tissue samples for toxic pesticides, PCBs, and trace metals. Most of the pollutants have shown trends of decreasing concentrations with time. DDT, DDE, DDD, and chlordane decreased significantly during the 1976-1984 period (Schmitt, Zajicek, and Peterman 1990), indicating low influxes and continued weathering in the environment. Since the Federal prohibitions and restrictions of the most toxic and persistent chlorinated compounds in the 1970s, other relatively low-toxicity and biodegradable organophosphorus compounds including diazinon; 2,4-D; 2,4,-5T; and atrazine have become the most prevalent and potentially problematic pesticides and herbicides in the lower Mississippi River. Chlorinated compounds in particular are extremely hydrophobic and are rapidly adsorbed to suspended sediment particles in the river, which gradually become deposited with bed sediments during moderate to low-flow periods. Rarely detectable in suspended sediment samples, they were measured at significantly lower concentrations in bed sediments of the lower Mississippi River by USGS in 1982 and 1983 (Demas and Curwick 1987) than in 1975 (Demas 1976).

Sediment and tissue samples from Lake Pontchartrain have not revealed unusual levels of synthetic organic compounds. Organochlorine compounds were rarely detected in water samples at the four referenced lake stations or in the Spillway during the 1979 floodwater diversion event. The only stations having above normal average concentrations of any compounds were Pass Manchac, (2,4-D); IHNC entrance (dieldrin); and the temporary station 9 miles from the outfall (DDT and dieldrin). The only organic compounds that appear to be of any possible concern in regard to freshwater diversions are 2,4,-D, atrazine, 2,4-5T, and certain other herbicides as well as diazinon and other comparatively nontoxic and nonpersistent compounds that have been substituted for the banned organochlorines. Atrazine has been cited as potentially toxic to aquatic plants and estuarine algae at concentrations above 10 $\mu$g/L. Its highest level among 20 samples from the Mississippi River at Baton Rouge in the spring of 1991, the most likely season for high-herbicide levels, was 3.6 $\mu$g/L.

The review of available data and trends and the continued control of industrial discharges through progressively restrictive permitting, enforcement, and monitoring activities indicate that organic compounds in diversion water would not be a significant threat to the lake. Detailed long-term studies of bioconcentration in the food chain or the bioavailability of sediment-associated compounds to benthos and other organisms have not been performed in Lake Pontchartrain. The low observed pollutant levels in lake sediments compared with other urbanized estuarine systems despite occasional large Mississippi River floodwater diversions, however, and the results of bioaccumulation and bioconcentration studies performed in much more polluted estuarine environments argue strongly against any significant long-term biological impacts in Lake Pontchartrain from organic chemicals.

## Trace Metals Assessment

Despite the large number of major industries that discharge wastewater into the river between Baton Rouge and New Orleans, little overall difference exists between the total recoverable and dissolved metals concentrations at the St. Francisville station, upstream of the industrialized reach, and the Luling station near the Bonnet Carre FWD Structure site. The imposition of stricter point source discharge requirements in accordance with the Federally mandated water quality-based drinking water and aquatic life standards, LDEQ's modernized surveillance and enforcement capabilities and voluntary efforts by many major dischargers to upgrade their treatment and control systems have limited industrial metals discharges to the river to the extent that total metals concentrations in the lower river have become more reflective of background sources within the basin than local sources.

The LDEQ Toxics Inventory Project has not revealed any mercury concentrations that have exceeded or approached the USFDA Alert Level among 72 fish tissue samples since 1991. The long-term USFWS fish tissue sampling station at Luling has shown no exceedences of the maximum safe concentrations of mercury among the annual averaged samples since 1969. Metals in general have been declining in the samples. Mercury and lead had statistically significant declining trends at the Luling station during the 1976-1984 period (Schmitt and Brumbaugh 1990). The decline in lead concentrations is attributed primarily to reductions in the lead content of gasoline and other fuels.

Trace metals are designated as priority pollutants by USEPA, which promulgates aquatic life criteria to provide adequate degrees of protection to biota. The most recent USEPA guidance on metals criteria (USEPA 1992) states that dissolved metal concentrations most nearly correspond to the biologically available fractions in natural waters. Dissolved trace metals in the lower Mississippi River have rarely violated their chronic or acute criteria in recent years. The typically high suspended solids levels in the Mississippi River, the complexing properties of manganese and iron oxide coatings on sediment particles, and the river's stable water chemistry condition collectively maintain consistently low dissolved metal fractions in the water column throughout the normal ranges of variation of solids levels and discharge.

Bottom sediment samples at Luling in 1982 and 1983 (Demas and Curwick 1987) revealed significantly lower average levels of copper and zinc than were measured at three sites in the lower river in 1975 (Demas 1976). Cadmium levels were about the same as before in the latter samples, and lead was undetected in both data sets. Comparisons of the averaged metal concentrations in the latter set to the USEPA Threshold Contaminant Concentrations for bulk sediment samples (Bolton et al. 1985) showed them to be below their thresholds by factors of about 5 to 17 (lead was assumed to be at one-half its detection limit). The averaged concentrations in both data sets were within or below the median ranges in the USEPA STORET database.

Dissolved trace metals levels at the active LDEQ sampling stations in Lake Pontchartrain at South Causeway, Mid-Lake, and Pass Manchac have rarely exceeded their aquatic life criteria. Cadmium, copper, and lead levels have been generally comparable with the lower Mississippi River levels. Flowers and Isphording (1988) focused on trace metals concentrations in Lake Pontchartrain bottom sediments. Similarities in the texture and mineralogy of the clay fraction to river sediments were noted. Those areas having the highest clay content were found to have the highest metals concentrations, and all metals except lead were positively correlated with the iron content of the sediments. Ion-partitioning analyses were conducted to estimate the potential for the metals to be released to the water column. Most metals were in relatively stable chemical phases. Metals that might be released upon resuspension of bottom sediments tended to be quickly scavenged by adsorption and coprecipitation reactions under prevailing water chemistry conditions and the abundance of fine sediments and their oxide coatings. The authors stated that shock loadings of metals from south-shore urban runoff discharges would eventually become adsorbed by the lake sediments either through scavenging or by other physicochemical processes and would have little potential for release back into the water column.

During the 1979 Spillway diversion period, the observed mean and maximum 6-day average concentrations of dissolved cadmium, copper, lead, and zinc at each of the four referenced lake sampling stations remained within their normal ranges of variation. Dissolved metals concentrations in both the river and lake have been consistently within the ranges that are considered normal for the region, with infrequent criteria violations. These data, the essentially unaffected metals concentrations in the lake during the 1979 diversion, the ref-

erenced studies and investigations, and the controls imposed on point discharges to the lower Mississippi River indicate little cause for concern regarding freshwater diversion impacts. The demonstrated tendency for metals to remain sediment bound and effectively unavailable to biota would in turn indicate that significant long-term bioaccumulation or bioconcentration effects are also unlikely.

### Temperature Assessment

Lake Pontchartrain temperatures are usually somewhat warmer than concurrent Mississippi River temperatures. When the effective response times for temperature during a springtime diversion are considered, however, the resulting gradients are substantially larger. During the 1979 Spillway diversion event, maximum lagged 6-day average temperature gradients of 9 to 11 °C were determined for the referenced lake sampling stations. The computed maximum 6-day average lake temperature reductions were between 2 and 4 °C. On the basis of historical data and the analysis of the 1979 diversion, it was estimated that the typical and worse case temperature reductions at a 9-mile distance from the FWD outfall would be about 1.6 and 2.4 °C, respectively. Frontal passages and other commonly occurring perturbations cause lake temperatures to be lowered by 2 to 5 °C within 1 or 2 days. In view of the much longer response times to diversion events except near the outfall, any temperature shock effects to biota would not be significant.

## Summary and Conclusions

The water quality assessment included the following major aspects:

- Review and statistical analysis of monthly Mississippi River and Lake Pontchartrain water quality data since 1979, which yielded representative monthly constituent levels for the quantitative assessments.
- Review of prior Corps of Engineers project study documents and other pertinent sources of information, including scientific studies and investigations in the project area and elsewhere that had become available since 1984.
- Contacts with persons in LDEQ, USGS, USEPA, and other agencies having expert knowledge of river and lake water quality and of important influencing factors and trends.
- Review and analysis of the 1979 Bonnet Carre Spillway floodwater diversion water quality and discharge database, which indicated which constituents might be problematic for the FWD project and resulted in empirical relationships of pollutant loading rates to lake water quality changes.
- Application of a site-specific population die-off rate to fecal coliform levels in diversion waters to estimate their with-project lake concentrations.
- Consideration of a projected "clean lake" condition for the urbanized south-shore area as it might influence the water quality impacts of freshwater diversions.

The primary focus of the water quality assessment was on the constituents believed most likely to cause criteria violations or otherwise adversely impact Lake Pontchartrain or impair its designated uses. Turbidity, nitrate nitrogen, total phosphorus, and fecal coliforms were assessed quantitatively for their effects on lake water quality using their respective median (50th percentile) and worse case (10th percentile) levels in Mississippi River water in combination with monthly project design flow conditions. The April-May 1979 Bonnet Carre Spillway diversion event offered the most direct and reliable means of quantitatively estimating the water quality effects of Bonnet Carre FWD structure operations since its discharge entered the lake at the freshwater diversion outfall site, and its occurrence coincided with the peak project diversion months. Toxic organic chemicals, trace metals, and temperature were determined not to be of concern to lake water quality.

The results of the assessments are summarized as follows:

- **Turbidity**. The maximum predicted median and worse case turbidity increases at any of the lake stations of 9 and 14 NTU, when added to typical ambient levels, showed that it would be unlikely for the LDEQ standard of 50 NTU to be exceeded in populated nearshore areas.

- **Nitrate**. The maximum predicted median and worse case nitrate+nitrite nitrogen increases at any station were 0.77 and 0.97 mg/L at the IHNC entrance, 0.41 and 0.57 mg/L at 9 miles from the outfall, and 0.08 and 0.11 mg/L at Mid-Lake. It is noted, however, that the predictions for the IHNC entrance are likely to be conservative because of the inherent assumption that the diversion plume's course would remain parallel to the south shore rather than drift more toward open water. During a year of project design diversions, it is estimated that about 24 million pounds of nitrate+nitrite would be delivered to the lake, or about 56 percent of the total 1979 floodwater diversion load. The lack of any reported eutrophying tendencies in the most impacted south-shore area would imply that the smaller, less intense FWD inorganic nitrogen loading would entail considerably less risk of overenrichment. Its inputs of significant volumes of nitrogen-rich river water should, however, result in enhanced primary productivity for the lake and its environs.

  A draft progress report of an independent study of nutrient impacts of the Bonnet Carre diversion project to Lake Pontchartrain commented that its stable oxygen regime and its net loss of grass beds do not support a eutrophic classification. The lake's natural turbulence and turbidity tend to suppress large diurnal DO variations. The report observed that the presently high N:P ratios in the lake allow other phytoplankton forms to compete favorably against blue-green algae for nitrogen. Since the diversions would further increase the N:P ratios, increased production of the noxious blue-greens and attendant adverse water quality effects would not be expected. The remainder of the nutrient study includes the following: further assessments of algal cell counts in phytoplankton samples; overlaying the phytoplankton and nutrient loading data on a two-dimensional model of the lake; and modeling diversion and hydrometeorologic scenarios to evaluate nutrient loading effects.

- **Phosphorus**. The maximum predicted median and worse case phosphorus increases of 0.06 and 0.07 mg/L would be too small to trigger eutrophication. The influxes should favor primary productivity.

- **Fecal coliforms**. The application of a 70-percent per day die-off rate for fecal coliforms in Mississippi River water to the peak project design flow of 30,000 cfs in April for median and worse case conditions revealed remaining levels of 35 and 77/100 ml at a 3-mile distance from the outfall and corresponding levels of 6 and 13/100 ml at the 7-mile distant St. Charles-Jefferson parish boundary. These values assumed that complete displacement of the lake water would occur, an increasingly unlikely condition with greater distances from the outfall and with smaller diversion flows. These tendencies would further reduce any predicted fecal coliform increases and would in fact help to improve nearshore water quality in urbanized Jefferson and Orleans parishes by diluting and dispersing discharged storm water. Any diversion-induced fecal coliform increases in Lake Pontchartrain should be small and well within ordinary ranges of variation except near the outfall.

- **Salinity**. Project design diversions would completely or virtually freshen some nearshore areas. Average lake salinity during the spring would be reduced below the average level that existed before the completion of the MRGO deep-draft channel in 1963. Southern

shoreline areas should generally benefit from the flushing action of the oxygen-rich diversion waters in the spring and summer. Freshwater fish species should increase in diversity and abundance in Lake Pontchartrain, but estuarine and marine species would be displaced to the east. Optimal salinity levels should prevail for oysters in the Bay Boudreau target area.

- **Toxic Organic Chemicals**. The review of monthly water quality data from Mississippi River sampling stations and from water, sediment, and fish tissue data from other monitoring programs and investigations by LDEQ, USGS, and USFWS demonstrated conclusively that toxic compounds in the lower river are rarely in violation of human health or aquatic life criteria. Federal prohibitions on use of the most toxic and persistent organochlorines since the 1970s and the implementation of progressively restrictive discharge permit requirements on industries and municipalities between Baton Rouge and New Orleans by LDEQ ensure the continued reduction of discharges of priority pollutants and other synthetic chemicals to the lower river. The only organic compounds that might appear to be of possible concern to lake water quality are certain herbicides that have become more prevalent as substitutes for banned organochlorines, but the highest observed levels in the lower river have been well below those known to be toxic to aquatic life. Nor do the available data in both the river and lake and the trends that have been observed indicate that bioaccumulation and bioconcentration effects of diversions would become significant.

- **Trace metals**. The imposition of more restrictive point source discharge requirements has limited industrial discharges such that total metals concentrations in the lower Mississippi River have become more reflective of background sources within the basin than local sources. A long-term fish tissue sampling program at Luling revealed generally declining metals concentrations, particularly mercury and lead. The most recent USEPA guidance on aquatic life criteria for metals states that dissolved metals most nearly correspond to the biologically available fractions in water. Dissolved metals in the river have rarely been in violation of their criteria in recent years, and USEPA research indicates that natural physical and chemical conditions in the river should maintain consistently low dissolved metals levels. Bottom sediment samples at Luling between 1975 and 1983 revealed significantly decreasing copper and zinc concentrations. A study of trace metals in Lake Pontchartrain bottom sediments showed that most metals were in relatively stable chemical phases, and that if released to the water column upon resuspension by wind waves, they tended to be quickly scavenged by the abundance of fine sediments. Dissolved metals concentrations in the lake were essentially unaffected by the 1979 floodwater diversion event. As for organic chemicals, bioaccumulation and bioconcentration concerns are minimal.

- **Temperature**. The analysis of Lake Pontchartrain temperature responses during the 1979 floodwater diversion enabled the estimation of typical and worse case temperature changes for a project design FWD event. Both the predicted temperature reduction of the lake water and its rate of cooling were found to be within the ranges observed during the passage of cold fronts and other meteorological events. It was thus concluded that temperature shock effects to biota would not be significant.

The review and analysis of lower Mississippi River and Lake Pontchartrain water quality data, the review of special studies and research reports, discussions with persons having expert knowledge of river and lake water quality conditions and trends, the adaptation of the water quality database of the

1979 Bonnet Carre floodwater diversion event to predictions of the water quality responses of certain potentially problematic constituents to Bonnet Carre FWD project design flow conditions, and the use of an experimentally determined die-off rate for fecal coliforms in diversion water were the essential elements of the WQA. The potential significance of nutrient impacts (nitrogen in particular) remained the only inadequately resolved issue with the completion of the WQA and EA in June 1993. The subsequent determination by an independent study that increased production of noxious algal blooms and their attendant consequences would not be expected provided satisfactory assurance that a Finding of No Significant Impact could be reached.

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# Water Quality and Water Control Issues for the Caernarvon Freshwater Diversion Project

*by*
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## Description of Project Area

The Breton Sound is a shallow, well-mixed estuary that forms part of a larger estuarine complex extending from the Mississippi River delta to the Mississippi Sound (Figure 1). The marshes and bays benefited cover an area of 77,000 acres. Levees have disrupted the natural processes of overbank flooding and distributary flow thereby depriving the adjacent wetlands of the annual influx of fresh water, nutrients, and sediments from the river.

The loss of wetlands and the deterioration of habitat quality have serious implications for all wetland resources. Coastal wetlands are the prime habitat of numerous waterfowl, furbearers, and alligators, not to mention the abundant fishery resources (Laiche 1991). Coastal wetland losses are due to a variety of factors, including channelization, saltwater intrusion, levee construction, subsidence, mineral exploitation, and sea level rise. Salinity, more than any other factor, determines the abundance and distribution of marine organisms. Without the annual spring floods, these coastal wetlands are almost totally dependent on rainfall for freshwater input. Though the east Mississippi River delta does provide freshwater benefits to the area, they normally arrive in the form of reduced gulf salinity and their greatest impact is seasonal in nature.

## Authorization and Construction

Caernarvon, the site of an old crevasse and strategically located at the head of the basin, was identified as a suitable site for diversions many years ago; a diversion was authorized by the Mississippi Delta Region Project in 1965. The structure contract was awarded on April 26, 1988, and was completed in February 1991. The structure consists of five 15- by 15-ft box culverts with vertical lift gates. The structure has a design capacity of 8,000 cfs. Though not required, the structure is capable of passing greater flows during favorable head conditions, but that would jeopardize the erosion protection that was designed for 10,000 cfs. The total cost of construction was \$25.9 million, with \$19.4 million as the Federal share and \$6.5 million as Louisiana's share.

## Interagency Advisory Group

The Caernarvon Freshwater Diversion Structure is managed by an interagency group of four State and four Federal agencies, representatives of two local governing bodies, and a landowner and a commercial fishery representative; the 12-member group meets at least yearly to decide general operating policy and review the structure's performance during the previous year. The participating agencies are shown below.

**Federal**
Corps of Engineers
Fish and Wildlife
National Marine Fisheries
U.S. Environmental Protection Agency

| State | Local |
|---|---|
| Natural Resources | Plaquemine Parish |
| Wildlife and Fisheries | St. Bernard Parish |
| Environmental Quality | Landowner |
| Health and Hospitals | Commercial Fishery |

[1] U.S. Army Engineer District, New Orleans; New Orleans, LA.

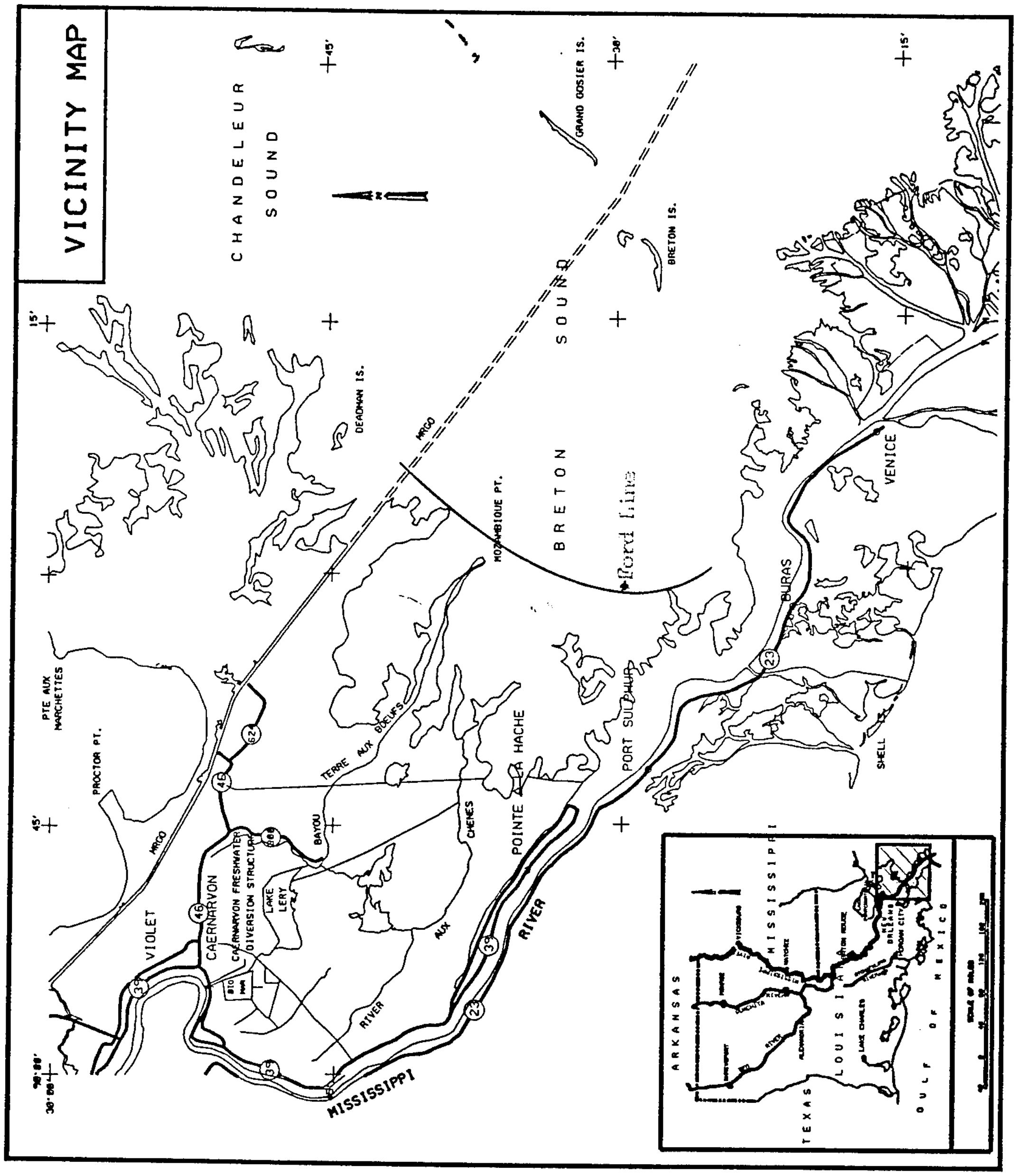


*Figure 1. Vicinity map*

## Technical Work Group

Day-to-day water control decisions are accomplished by a five-member group that consists of the Corps and the State agencies. Decisions center around safely accomplishing monthly target salinities while minimizing negative impacts. In addition, this group is tasked with the technical evaluation of all data and recommendations involved with the operation and impacts of the structure.

## Operational Management Plan

The Operational Management Plan is a set of criteria used to guide the structure's operation. During the Reconnaissance and Feasibility Study phases, the Ford Line criterion was used. The Ford Line defines the position of the 15 ppt mean isohaline from spring through fall (Figure 1). This criterion was not based on documented conditions but rather on conditions deemed desirable by an interagency ad hoc group (circa 1970) (Chatry and Chew 1984). During the General Design phase, monthly salinity targets identified by Chatry, Dugas, and Easley (1983) were adopted. Those monthly salinity values were shown to be beneficial to oysters and were consistent with the Ford Line criterion, which is also beneficial to the coastal wetland resources in general.

The adopted monthly target salinities, shown below, were developed from a study conducted by Louisiana Department of Wildlife and Fisheries (LDWF) biologists in this estuary. The study correlated the monthly salinity at the State's seed oyster grounds with the years of high oyster production. The three stations used in the study to compute monthly average salinity were adopted similarly for water control purposes.

Each year since the structure became operational, the management plan has been amended. On one occasion, the May target was adjusted upward in an effort to boost brown shrimp production; but in the following year, the target was lowered again. The most notable change in the plan has been to operate the structure at the maximum diversion rate (8,000 cfs) for the months of December, January, and February; this plan, though consistent with the Ford Line criterion because it occurs during the winter months, has drastically changed the salinity regime and ecology of the estuary during that period.

| Month | Salinity Target, ppt |
|---|---|
| January | 16.4 |
| February | 14.4 |
| March | 11.6 |
| April | 8.0 |
| May | 7.0 |
| June | 12.5 |
| July | 12.7 |
| August | 15.7 |
| September | 17.0 |
| October | 16.8 |
| November | 16.1 |
| December | 15.7 |

## History of Structure's Operations

The structure's ability to affect the estuary's salinity regime has been consistently demonstrated throughout the performance life of the structure. When supplemental flow is not required to achieve target salinities, a base flow is maintained to keep salinity in the fresh-to-brackish range in the upper basin. Because the targets vary sometimes widely from month to month, attention is given to natural seasonal variations and other meteorological forcings that may have a short, i.e., 7 to 14 days, term influence. Cultivating the proper perception, balancing the importance of each resource, blending the talents of all involved, and working with a high ethic have ensured successful operations.

## Describe Monitoring Programs

The monitoring plan envisioned and implemented for the project was to be conducted in two phases: a 3-year preconstruction phase and a 4-year postconstruction phase. The preconstruction phase was used to collect further baseline hydrologic and biological data. The postconstruction data will be used to evaluate

the short- and long-term effects of the diversion on the hydrologic regime, the coastal ecology, and the wetland resources (U.S. Army Corps of Engineers 1986).

The "Water and Sediment Quality" and the "Hydrologic" monitoring programs are managed and conducted by the Corps. These programs included the collection of data to characterize the sediment quality in the outfall area, to profile the water quality in the basin, and to quantify hydrodynamic parameters for use in numerical modeling studies in defining/refining a water control operational model for the structure.

The "Biological" monitoring program was implemented by the Louisiana Department of Wildlife and Fisheries, which had an existing monitoring program in place in the basin. This program included the collection of transect data on marsh vegetation and population data on waterfowl, furbearers, alligators, finfish, and shellfish.

## Water Control Operation and Performance

Water control activities are decided by the Technical Work Group and implemented by the Structure Operation Manager, who is with the Louisiana Department of Natural Resources. Gate changes are made by Plaquemine Parish, which operates the structure for the State.

Water control decisions are based on factors that include seasonal fluctuations in Mississippi River discharges, rainfall, synoptic weather patterns, deviation from target salinity, projected salinity trends, salinity transect data, tidal cycle response, and data collection platform data (via satellite). Salinity response curves developed from numerical model studies during the preconstruction period along with operational experience data provide the basis for making flow determinations.

Communication between group members is accomplished mostly via telephone and fax, though meetings and field trips are also held to discuss nonroutine noteworthy and complex issues requiring special attention.

The Waterworks Warning Network, a warning system for water supplies along the lower river to identify spills or other detriments, has helped to prevent the accidental introduction of contaminants into the estuary. Emergency closures are also initiated when hurricanes or tropical depressions are present in the Gulf of Mexico.

## Special Issues

A number of special issues and problems have emerged that have served to both challenge and frustrate. A few instances are recounted below:

The original project purpose must be kept in focus when making changes to the Operational Management Plan. Operational Management Plan changes must be consistent with the Environmental Impact Statement (EIS); if not, a Finding of No Significant Impact or supplemental EIS must be prepared.

During the report phases of the project, nutria (furbearers) were expected to benefit from the project; since they were hunted for their pelts, their populations would be checked. Since project construction, however, the demand for pelts, because of the animal rights movement and other market forces, has declined. As a result, a population boom of marsh-eating nutria has emerged.

Marsh-munching is only one of the problems attributed to the nutria; fecal coliform counts much higher than those introduced in the Mississippi River are being recorded throughout the basin and are attributed to the nutria. The seasonal closure lines for marketing oysters is tied to this parameter; as the Health Department's database acquires more values exceeding the shellfish criterion, the oyster closure lines will creep seaward.

One unexpected ecological change is the overabundance of submerged vegetation in

the basin; though it was initially thought that it was attributable to the influx of fresh water and nutrients from the structure, it has now been identified with a statewide bloom of cyclical nature. This has become a nuisance to boaters, fishermen, and oystermen; however, it does stabilize the substrate and serve as a nursery area for fish and shrimp.

It was envisioned that floating debris accumulating at the face of the structure in the inflow channel would be removed by crane as it became necessary. However, structure operations have revealed that accumulated debris will be swept downstream when the structure is closed for a day.

## Conclusion

The Caernarvon Freshwater Diversion Project has served its authorized purpose of controlling salinity in the Breton Sound Estuary. Moreover, the interdisciplinary approach to water control management, in this case, has proven to be not only effective but necessary for the successful operation of the project.

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# Corps of Engineers Involvement in Atlantic Salmon Restoration on the West River

*by*
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## Historical Conditions

In precolonial times, at least 28 major rivers in New England contained significant Atlantic salmon populations. The number of adult salmon entering these rivers annually may have exceeded 300,000 individuals. Largest populations were found in the Connecticut, Merrimack, Androscoggin, Kennebec, and Penobscot rivers.

Salmon populations continued to thrive during the colonization of New England, but were severely reduced by the early nineteenth century because of dam construction and overfishing. Salmon were eliminated from the upper Connecticut River by a dam built at Turners Falls, MA, in 1798. This dam prevented adult salmon from reaching about 70 percent of available nursery habitat in the river. Continued river development and commercial fishing pressure reduced populations still further until 1865, when salmon runs had been eliminated in southern New England and reduced to remnant populations in Maine.

Efforts were made to restore salmon in the Connecticut and Merrimack rivers in the latter part of the 1800s. In 1867, a joint venture by Massachusetts, Connecticut, New Hampshire, and Vermont was begun to restock the Connecticut with fish from Maine and Canada. In the following years, hundreds of thousands of juvenile Atlantic salmon were released into Connecticut River tributaries, and at least 800 adults returned. After completion of a fishway at Holyoke Dam in 1873, restocking efforts occurred primarily in the main stem of the Connecticut River.

Restoration efforts met with only partial success and were abandoned in the 1890s because of inadequate upstream fish passage facilities, declining water quality, and the inability of the States to control fishing. Additionally, many fish ladders were destroyed by floods in 1890.

Creation of the Maine Atlantic Sea-Run Salmon Commission in 1947 marked initiation of contemporary efforts to restore salmon in New England. Passage of the Anadromous Fish Conservation Act by Congress in 1965, at a time when water quality was improving in our rivers, resulted in a rapid expansion and acceleration of salmon restoration efforts throughout New England. The act enabled State fishery agencies to obtain Federal funds on a cost-sharing basis for restoration activities.

Atlantic salmon presently enter 16 river systems in New England. In recent years, the total adult salmon population has varied between 3,000 and 7,000 individuals, of which an estimated 1,500 to 2,500 resulted from reproduction in the wild, with the remainder being of hatchery origin.

Although a number of rivers in all six New England states are targeted for salmon restoration, efforts are concentrated on the Penobscot in Maine, the Merrimack in Massachusetts and New Hampshire, and the Connecticut River in Connecticut, Massachusetts, New Hampshire, and Vermont.

[1] U.S. Army Engineer Division, New England; Waltham, MA.

## Salmon Restoration in the Connecticut River

The largest river in New England, the Connecticut, is about 400 miles long with a drainage area of 11,250 square miles. It is home to more than 2 million people, primarily in urbanized areas of Connecticut and Massachusetts; however, this is not reflected in overall land use, which is 79 percent forested, 13 percent agricultural, and only 4 percent urban. Water quality has been a problem for many years, but has improved significantly since the 1960s.

Although it is near the southern end of the salmon's range, the Connecticut River is very important in restoration plans. The river and its tributaries contain the largest amount of potential salmon nursery habitat in New England (267,000, 100-square yard habitat units). The basin has the potential to produce at least 530,000 juvenile salmon per year. Based on historical records and the amount of nursery habitat, precolonial returns of adult salmon to the river likely ranged between 70,000 and 140,000.

The present Connecticut River salmon restoration program began in June 1967 when the Connecticut River anadromous fish program became a cooperative Federal-State endeavor after the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service, Connecticut, Massachusetts, New Hampshire, and Vermont signed a formal agreement to support fisheries programs for the river. During the fall of 1979, the U.S. Forest Service became a participant in an advisory position. The goal of this program is to provide and maintain a sport fishery for Atlantic salmon in the Connecticut River basin and restore and maintain a spawning population in selected tributaries. To achieve this, the program had objectives of achieving an adult population of 7,500 salmon returning to the mouth of the Connecticut River and a sport harvest of 4,000 salmon, and maintaining an effective spawning population of 5,500 Atlantic salmon.

Approximately 30 Connecticut River tributaries are targeted for restoration. Nine of these, including the West River in Vermont, are expected to support natural salmon reproduction. The remainder will be entirely dependent on stocking programs, at least initially.

To accomplish these goals, efforts have focused on construction of fish passage facilities on main stem Connecticut River dams, and intensive stocking with hatchery-reared fry, parr, and smolts. To date, fish passage facilities have been constructed at all five main stem Connecticut River dams and at several dams on tributaries. In recent years (1987-1993), over 10 million hatchery-reared fry have been released in the basin.

An average of about 200 adult salmon have returned to the Connecticut River since 1986. Most returning adults are captured in fish passage facilities and retained for captive propagation. Larger returns are anticipated in coming years as a result of heavy fry stocking instituted in the late 1980s. Many of these fish will be allowed to spawn naturally.

## Salmon Restoration in the West River

At mile 149, the West River enters the Connecticut River from Vermont. Fifty-two miles long with a drainage area of 423 square miles, the watershed is hilly and generally forested and undeveloped. The riverbed is fairly steep: from its source to the Connecticut River, the West River drops about 52 ft per mile. Water quality is excellent.

Although historical records are scant, it is likely the West River once supported a large Atlantic salmon population. One historian reports that the Squakheag Indian name for the junction of the West River was the "salmon spearing place." The story is that salmon once ran so thick one could almost walk across the river on their backs.

The West River and its tributaries contain about 9 percent of available salmon nursery

habitat in the Connecticut River basin. The river ranks third among Connecticut River tributaries in potential nursery habitat and second for potential production of wild (nonhatchery-reared) salmon.

Several hundred thousand fry have been stocked in the West River and its tributaries each year since 1987. Studies by the Vermont Department of Fisheries and Wildlife indicate that survival of stocked fry is excellent. Although no studies of smolt production are yet available, large numbers are likely to emigrate from the river each spring. About 15 adult salmon have probably returned to the river to spawn since 1989. Based on available nursery habitat, eventual returns of 550 adults per year are expected.

Two Corps of Engineers flood control dams, Townshend Lake and Ball Mountain Lake, are present on the West River. Both dams were obstacles to upstream migration of adult salmon. Ball Mountain Dam was also thought to impede downstream migration of young salmon (smolts). Modifications to both dams were essential to salmon restoration in the West River since 60 percent of West River salmon habitat is upstream of Ball Mountain Dam and 80 percent is upstream of Townshend Dam.

In 1989, Congress authorized the Corps to spend 1.4 million dollars to provide upstream and downstream passage for salmon at the two projects. The Corps completed feasibility-level studies in February of 1992 and project construction in the spring of 1993.

## Salmon Life History

Designing facilities for upstream and downstream passage requires an understanding of the salmon's life cycle.

Unlike the Pacific coast, which is home to a number of species, there is one species of Atlantic salmon in New England, *Salmo salar*. It is anadromous, reaching maturity in salt water but reproducing in fresh water.

Adult Atlantic salmon return to the Connecticut River in spring and generally reach the West River from late May through mid-July. Once near the West River, salmon either remain near the Connecticut River confluence or seek out cool, deep-water habitat further upstream. Fish may not complete migration to spawning areas until fall. For this reason, upstream passage must be provided from late May through fall.

Spawning occurs in late October through November. During spawning, the female salmon chooses a gravel area and excavates a pit called a redd in to which eggs are deposited.

Unlike Pacific salmon, Atlantic salmon do not necessarily die after spawning. Adult fish that have spawned are called "kelts" and may return to the sea immediately or, more typically, during the following spring. Only a very small portion of the kelts will successfully make the journey back to salt water and return again as repeat spawners. Exact length of the reproductive life is not known.

Salmon eggs deposited in the redd normally hatch in late March and April, followed several weeks later by the emergence of fry from the gravel (fry are stocked primarily in May). After reaching a length of about 40 mm, juvenile salmon strongly resemble juvenile brown trout in appearance and are called "parr."

In New England rivers, parr remain in fresh water for a period of 1 to 3 years before undergoing the physiological changes (smoltification) that prepare them for migration to the ocean. At this stage, the fish, now called "smolts," are a silver color. Wild smolts typically are 12 to 15 cm long; hatchery smolts are somewhat larger. Migration probably occurs from mid-April through May.

Once the smolts enter the ocean, they migrate to distant feeding grounds, frequently north of the Arctic Circle. The salmon spend 1 or more years at sea before returning to their natal stream.

Fish that return after one winter at sea are called "grilse" and are considered poor brood stock because of their small size. The majority of salmon will spend two winters at sea and are referred to as "salmon" or "multiyear" fish. These typically are 60 to 90 cm long and weigh 3 to 6 kg at the time of return.

## Existing Facilities and Fish Passage Problems

### Townshend Lake

Townshend Lake is located on the West River about 19.5 miles above its confluence with the Connecticut River. The dam is a 1,700-ft-long rolled-earth and rockfill embankment, with a maximum height of 133 ft. Outlet works consist of an intake structure, three 7.5- by 17-ft control gates, a 540-ft-long horseshoe conduit through the dam, and an outlet channel. A weir located upstream of the central flood control gate maintains a permanent 21-ft-deep conservation pool. The weir is a box-inlet structure 18 ft wide on the end and 20.5 ft long on the sides.

Outlet works configuration prevents upstream migration of adult salmon. Although they might be able to enter the discharge conduit at low flows, the weir would prevent passage into Townshend Lake. Emigrating smolts easily pass over the weir, but could be injured by the 21-ft drop.

### Ball Mountain Lake

Ball Mountain Dam is located on the West River about 9.5 miles upstream from Townshend Lake and 29 miles upstream from the Connecticut River. The dam consists of a 918-ft-long rolled-earth and rockfill embankment with a maximum height of 265 ft. Outlet works consist of an intake structure with three 5 ft, 8 in.- by 10-ft gates and an 864-ft-long 13.5-ft-diam conduit through the dam. A 65-ft conservation pool was normally maintained during late spring and summer. The pool is lowered to 25 ft from fall through early spring to prevent gates from freezing.

Configuration of Ball Mountain Dam's outlet works also prevents upstream migration of adult salmon. Although they might be able to enter the discharge conduit at low flows, high velocities at the gates would prevent passage into the lake. During the spring smolt migration period (late April through May), the 65-ft pool would likely prevent smolt emigration. It is unlikely smolts would sound to 65 ft; if they did, pressure changes during passage through the gates would result in substantial mortality.

## Modifications to Provide Upstream Passage

A number of ideas were proposed for upstream passage before settling on trapping fish below Townshend and trucking them around one or both dams. This plan also makes for effective passage past two other dams upstream from Ball Mountain.

Below Townshend Dam, a barrier stops fish and directs them towards a trap. This barrier is 120 ft long, angled 50 deg across the river, and made of twelve 10-ft-wide grates. Figure 1 shows the barrier. Nine of these grates are 6 ft high, and three are 7 ft high because of a low-flow channel in the right side of the structure. Dimensions of this low-flow channel approximate natural conditions in the stream. Grates are made of galvanized 5/8-in. bars spaced to give 1.5-in. clearances. This width should prevent passage of adults through

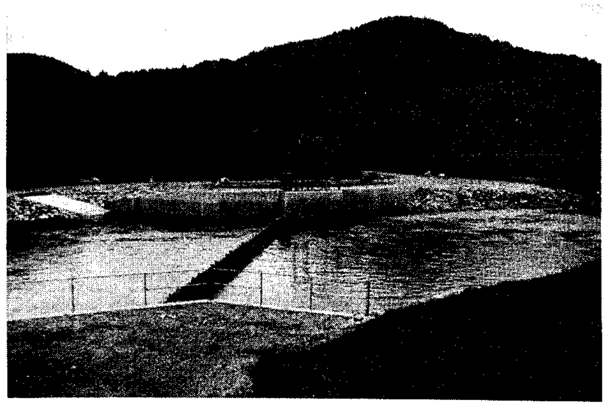

*Figure 1. Fish barrier below Townshend Dam*

the barrier while allowing smolts to pass freely. Grates are hinged for lowering during high flows.

The fish trap is 6-1/2 ft wide and located on the right-hand side of the barrier. The main part of the trap is the holding area, which has a grated floor that can be raised to force fish into the lifting bucket for loading into a truck. Invert elevation of the downstream opening is designed to provide sufficient depth of water for fish under low-flow conditions. Additional features include upstream racks to stop the fish and a downstream V-shaped bar rack pointing upstream towards the holding area. This rack has an opening at its apex to allow fish to enter but not leave the holding area. There is also a downstream gate to control velocities through the structure. Upstream and downstream racks are made with the same bars and spacings as the barrier racks. Entrance to the fish trap can be closed, and lights and a security fence are provided. Figure 2 shows the fish trap.

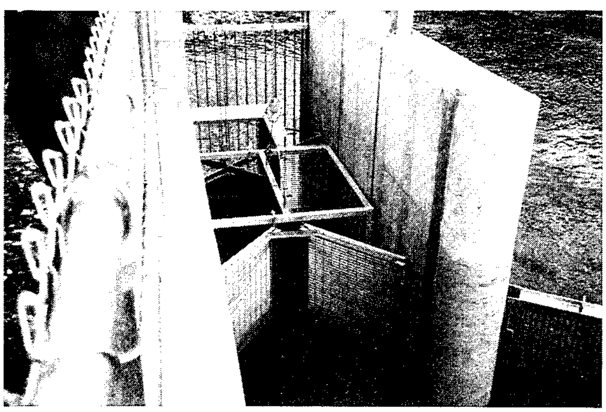

*Figure 2. Fish trap on right side of barrier*

Design flow for upstream passage is 1,500 cfs. At higher flows, fish are not expected to move upstream. At 1,500 cfs, the barrier should be 1 ft higher than the downstream level of the river. This should prevent fish from leaping the barrier, unless a hydraulic jump forms; when salmon encounter a sudden increase in water velocity, it can stimulate them to jump. At 1,500 cfs, flows in the trap's holding area will be less than 2 ft per second to avoid stressing trapped salmon.

The barrier is designed to withstand flows up to 5,000 cfs when 25-percent clogged with debris. Excessive debris blockage will interfere with downstream passage. Also, if debris blockage causes enough head drop for a hydraulic jump to form below the racks, upstream migrating fish could be stimulated to jump. Therefore, it is very important that the barrier be kept relatively free of debris.

Grates should be lowered for releases greater than 5,000 cfs. Maximum nondamaging discharge from the project is 9,000 cfs. Maximum discharged recorded at the dam was in excess of 10,000 cfs during the May 1987 floods. At that time, spillway discharge occurred; however, spillway flows join the river below the fish trap, and 9,000 cfs is the maximum the trap is likely to encounter. At that flow, pins holding the grates in place are supposed to fail, dropping the grates. Flooding that would occur if the pins do not fail would limit access to the fish trap and possibly damage the earth access road, but do no serious harm. As it takes a tractor and two people to lower the grates, they may not always be lowered before large reservoir releases need to be made.

The trap will be operated from mid-late May through October. Plans call for raising the barrier a few days after salmon are known to pass through Vernon Dam, the last main stem Connecticut River dam downstream of the West River confluence. Most smolts and kelts should pass downstream before the barrier is raised. Any kelts passing downstream after the barrier is raised would be trapped between the barrier and dam. However, the number of downstream moving kelts that would survive and return in future years is expected to be too small to influence design or operation of the facility.

## Modifications to Provide Downstream Passage

### Ball Mountain Lake

To provide downstream smolt passage through Ball Mountain Lake, it was decided to lower the pool from 65 to 25 ft during the smolt emigration period. Other alternatives, such as completely draining the pool during the smolt emigration period or constructing an outlet weir or upstream smolt trap, were rejected because of environmental or cost considerations.

Maintaining a 25-ft pool at Ball Mountain Lake during the smolt emigration period should ensure that smolts pass through the dam with minimal delay or mortality. This conclusion is supported by Corps-funded USFWS studies using radio-tagged smolts in 1990 and 1991. Both studies found that smolts quickly pass through Ball Mountain Lake (with a 25-ft pool), with average delays of just 2 to 6 hr. The 1991 studies found that smolts passing through the dam probably suffered little or no mortality.

Vermont's Department of Fish and Wildlife initially requested Ball Mountain Lake be lowered to 25 ft from early April through May. This "window" would encompass the entire smolt emigration period since peak emigration probably occurs in the West River from mid- to late April through mid-May. However, two constraints prevented adoption of this window. The first was that maintaining a constant 25-ft pool in early April would be extremely difficult because of hydrologic conditions and flood control constraints. The second was that lowering the pool before late April would preclude controlled releases for whitewater recreation below Ball Mountain Lake.

Each year the Corps provides controlled releases from Ball Mountain Lake for white-water canoeing and kayaking. Prior to 1990, controlled releases were typically made during two weekends in the spring (late April and early May) and during Columbus Day weekend in October. The releases provided outstanding white-water conditions between Ball Mountain and Townshend Lakes and additional recreation below Townshend. Hundreds of white-water enthusiasts came each year. The National White-Water Canoeing Championship Races were frequently held in the West River during one of the spring release weekends. However, spring storages and releases were made at the projected time of peak smolt emigration. In fall 1990, an informal agreement was worked out among the Corps, USFWS, Vermont Fish and Game, and the Appalachian Mountain Club that there would be only one spring release for recreation. The pool would be held to 65 ft until the last weekend in April when white-water recreation releases would be made. The pool would be kept down until 1 June, at which time it would be raised to the summer pool level of 65 ft. Races were held at other locations and are not currently scheduled to be held at Ball Mountain Lake in future years. This plan may be modified as more information about timing of smolt emigration becomes available.

Several issues were raised regarding implementation of the proposed plan. One concern was that the lowered pool at Ball Mountain exposes large areas of mudflats between the levels of the 25- and 65-ft pools. These mudflats are unsightly and could lead to excessive erosion and downstream turbidity during rainstorms. During the winter when these mudflats are exposed, they are also frozen, which gives them stability they would not have in the late spring. However, monitoring during the experimental smolt release studies indicated minimal increases in turbidity.

A second concern was that it may not be possible to restore the summer pool for a long period of time during dry years. This would be an aesthetic problem because of the "bathtub ring" that would be exposed. There is no significant fishery or recreational resource at Ball Mountain Lake to be harmed by fluctuating pool levels.

A third concern was raised by the flashy nature of the watershed and narrow V-like valley immediately behind Ball Mountain Dam. These cause the pool to rise and fall very quickly following runoff events. Consequently, manual operation of flood control gates to maintain a 25-ft pool is very labor intensive. Installation of an automatic gate was planned to maintain the pool at the 25-ft stage during the downstream migration period.

### Townshend Lake

USFWS studies showed that radio-tagged smolts pass through Townshend Lake with little delay. The main concern about downstream passage was that fish would be injured going over the weir and landing on the concrete floor of the outlet passage. Consequently, a 3-ft-deep splash pool was created at the base of the weir using a frame lowered in the emergency gate slots. Additionally, a 1- by 1-ft notch was cut in the weir in front of the center gate to provide additional depth and attraction velocity over the weir during low flows.

Concerns were raised about impacts of the splash pool on reservoir-discharge capacity and possible cavitation effects. Installing a 3-ft barrier in the conduit between the weir and gate was found to have no effect on discharge capacity. The 3-ft barrier is too low to affect flow over the concrete weir. When flow backs up from the gate and submerges the weir, there is enough opening above the barrier that it does not form a restriction in the entrance channel to the gate.

Turbulence created by the barrier possibly could cause cavitation when high flows are released through the center gate. Consequently, when the barrier is in place, large releases will be made through the two outside gates. This will also reduce chances that the 3-ft barrier would be damaged by floating debris. Using only the outside gates for large releases should present no real problems as these gates have sufficient discharge capacity.

## Project Status

Initially, the New England Division had 1.4 million dollars to design and construct the fish ladder. This was later reduced to 1.23 million. Planning, engineering, and design used $510,000; construction cost $565,000; $70,000 was set aside for construction supervision; and $85,000 was budgeted for contingencies.

The project was constructed during the summer of 1992 through spring of 1993, with most in-river work completed by November. Originally, it was expected construction would take two seasons; however, the schedule was accelerated to minimize disruption to the river and start collecting salmon as early as possible. Additionally, the contractor was able to save considerable time by using fabric-frame “portadams” instead of earth cofferdams. Use of these portadams also minimized environmental impacts at the construction site.

In spring 1993, construction of fish passage facilities at Ball Mountain and Townshend Lakes were formally completed, and on 18 June, the first adult salmon was trapped, transported, and released upstream of the dam at Townshend Lake. It was a 30-in. fish. Two other fish appeared at the trap later in the spring. One somehow got to the upstream side of the barrier and was found dead against the racks. The other appeared at the barrier and swam back and forth without entering the trap. It later disappeared. At the time, flow through the trap was restricted by a piece of plywood used to replace a damaged gate.

## Operational Problems

Several problems were noted during the first season of operation. Collection of debris on the trap and barrier was heavier than anticipated. During high-flow periods, the barrier needs to be cleaned every few days. A hydraulic jump caused by collection of debris on the barrier may have been responsible for

the salmon that apparently leaped over the barrier. A revised log boom upstream from the dam and a trash-collection boom between the dam and barrier are being considered.

Rocks, moved downstream by high discharges from Townshend Dam, damaged a barrier grate during the winter of 1993. These rocks originated in a scour hole at the base of the dam. Plans are being developed to repair the scour hole and possibly install a stilling basin.

Numerous white suckers migrating downstream were trapped and killed by the barrier. If this problem continues, it may be necessary to increase clearances in the downstream-most barrier grate to facilitate white sucker passage. It should be possible to do this without greatly increasing the risk that salmon will pass through the barrier.

Problems were encountered during initial setup of the automatic gate mechanism at Ball Mountain Dam, and on 8-9 May 1993, the water-level sensor malfunctioned, causing the pool to drop from 24.6 to 6.4 ft overnight. Normally, Ball Mountain's pool does not go below the 25-ft stage, and there was a large deposit of sediment behind the dam at that depth. When the sensor malfunction caused the pool to drop so far and fast, a large amount of sediment was released downstream. Much of this material was fine sand, and it resettled in the river between Ball Mountain Dam and Jamaica State Park, a distance of a couple of miles. Normal streambed below the dam consists of gravel and cobbles; however, sediment produced sandbars, filled spaces between rocks, and greatly reduced depths at two swimming areas at the State Park. Between the State Park and upper reaches of Townshend Lake, the normal stony stream bottom gradually reappeared.

There was considerable concern about effects of this sediment on aquatic life in the stream, especially trout and juvenile salmon. It was a very dry summer, with little flow to move the sediment. Some was moved by fall recreation releases, and it is hoped spring snowmelt releases will flush out the remainder.

## Summary

As a total of only three adult salmon have appeared at the barrier, it is too early to judge effectiveness of upstream passage facilities. Additionally, although initial tests with radio-tagged smolts indicate good downstream passage should be achieved, no counts of downstream migrating fish have been made. Consequently, overall performance of fish passage cannot be evaluated yet. Although there are maintenance problems associated with debris removal, it appears the design will work well.

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# Water Releases from Jim Woodruff Dam and the Threatened Gulf of Mexico Sturgeon

*by*
*John E. Zediak*[1] *and Joanne U. Brandt*[1]

## Introduction

As the nation's infrastructure continues to age, many Federally owned dams may have the opportunity to upgrade older less efficient hydroelectric turbines with newer models. More efficient turbines require less water to produce the same amount of electricity than most older turbines, providing more appealing conditions for management of the available water. The end result would be more water available for authorized project purposes and if necessary, any future purposes, compared with the conditions prevalent during operation of the existing turbines.

Over time, we have also gained much knowledge of the effects of our past actions and have developed more understanding of the impact of those actions on the environment and the creatures that surround us. This has brought about legislation such as the Endangered Species Act of 1973, which provides for protection, under Federal law, of an ever-increasing number of species.

Jim Woodruff Lock and Dam is scheduled for major rehabilitation work that includes replacement of the existing hydroelectric turbines with newer more efficient models. The rehabilitation will not change the net flow through the dam, but may alter localized flow patterns and velocities immediately downstream of the dam because of the powerhouse's ability to accommodate broader ranges of flows. Concern has been raised by the U.S. Fish and Wildlife Service and the Florida Game and Fresh Water Fish Commission that an alteration of localized flow conditions in the tailwater area downstream of the dam may impact the needs of the threatened Gulf of Mexico sturgeon (*Acipenser oxyrhynchus desotoi*).

This study examines data from past and existing flow conditions through the powerhouse and through the adjacent spillway at the times when Gulf sturgeon population surveys were being conducted by the U.S. Fish and Wildlife Service. The objective will be to identify any relationship between the type and rate of release through the dam and the number, characteristics, and specific locations of the sturgeon that were caught. The data would also contribute in preparing a Biological Assessment as required under the consultation requirements of Section 7 of the Endangered Species Act of 1973.

## Background

Jim Woodruff Lock and Dam is located 37 miles northwest of Tallahassee, FL, on the Apalachicola River approximately 106 miles upstream from its mouth at the Gulf of Mexico. The Apalachicola River flows from Jim Woodruff Dam south through the panhandle of Florida to the Gulf of Mexico. The dam impounds water from the Chattahoochee and Flint rivers to form Lake Seminole, located at the southwest corner of Georgia on the Georgia-Florida State line. Lake Seminole encompasses approximately 37,500 acres extending approximately 47 miles up both the Chattahoochee and Flint rivers. The lock and dam project was completed in 1957, with major features being a fixed-crest spillway, lock, powerhouse, and gated spillway. It impounds 367,000 acre-ft of water which, in the

[1] U.S. Army Enginner District, Mobile; Mobile, AL.

project's design specifications, created a head of 33 ft between the pool and tailwater.

Jim Woodruff Lock and Dam was originally authorized for development of navigation and hydroelectric power in the Apalachicola-Chattahoochee-Flint River Basin. Today, it is a multipurpose project with authorized purposes of fish and wildlife conservation, hydroelectric power generation, navigation, water quality, and recreation. The project is currently managed and operated for fish and wildlife conservation, hydroelectric power generation, navigation, water quality, and water supply (U.S. Army Corps of Engineers (USACE) 1992).

## Powerhouse

The powerhouse consists of three turbines that are the original units, installed in 1957. They are rated at a total capacity of 30,000 kW, originally capable of discharging 18,300 cfs at a normal pool elevation. The powerhouse is operated as a run-of-the-river plant with daily generation being determined by the water available for discharge after all operating purposes have been considered. This typically results in the turbines being operated continuously and often at reduced capacity. The reduced capacity is achieved by controlling the flow of water to each turbine by closing the wicket gates that encircle each turbine's blades. The particular turbines at Jim Woodruff's powerhouse, by original design, continuously adjusted the angle of the turbine blades to achieve the maximum capacity possible at any wicket gate setting. However, because of mechanical problems with the mechanism that changes the blades' angle, all blades have been welded in a fixed position. This has the overall effect of reducing the turbine's efficiency because the turbine can no longer achieve the maximum capacity at the various wicket gate settings (USACE 1993).

## Tailwater Degradation

The foundation upon which the structures at Jim Woodruff Lock and Dam are constructed is limestone. Limestone is a typical rock formation in southern Alabama, southern Georgia, and Florida. In the vicinity of Jim Woodruff Dam the limestone ranges from soft to moderately hard. At the tailwater and the area directly downstream, erosion caused by high-energy water discharged from the dam has caused a larger head during low flows than the turbines were originally designed to operate. This causes a severe vibration problem under minimal discharge situations and forces the switching of turbine flow to spillway flow, which results in the loss of hydropower benefits. Degradation of the tailwater and the welding of the turbine blades have caused an estimated 17-percent (36,000,000-kW hr) loss in the plant's average annual output and the resultant revenue (USACE 1993).

## Gulf Sturgeon

The Gulf sturgeon is a subspecies of the Atlantic sturgeon that historically has occurred in the waters of the Gulf of Mexico and freshwater rivers that flow into the Gulf of Mexico. It is a primitive fish with bony plates (instead of scales) that matures slowly but is long-lived. Adults may reach a length of 6 ft or more and feed on bottom-dwelling invertebrates such as worms, insect larvae, and crustaceans (Barkuloo 1988).

The Gulf sturgeon has a long history of existence in rivers such as the Suwannee and Apalachicola rivers of Northwest Florida. It is an anadromous fish known to travel from the Gulf of Mexico into freshwater rivers in the spring to spawn, where they remain until the fall months before returning to Gulf waters. On the Apalachicola River, the physical barrier created by Jim Woodruff Dam prevents the migration of the Gulf sturgeon upstream to the Chattahoochee and Flint rivers, which the sturgeon had previously utilized for spawning. Deep holes and cool-water springs downstream of Jim Woodruff Dam provide important thermal refuges for the Gulf sturgeon. Deep holes with clean bottoms of rock, gravel, or sand likely also provide spawning habitat. A summary of the "commercial sturgeon" landings

in the Gulf of Mexico, for the area of West Florida from 1951 to 1985, is depicted in Chart 1. The term "commercial sturgeon" refers to all sturgeon caught, but it is believed that the majority of these were Gulf sturgeon (Barkuloo 1988).

ommended alternative, based on technical and economic feasibility, was an option for replacing the existing turbines and rewinding the generators without construction of a tailwater weir. This alternative would likely result in turbine discharges similar to those experienced

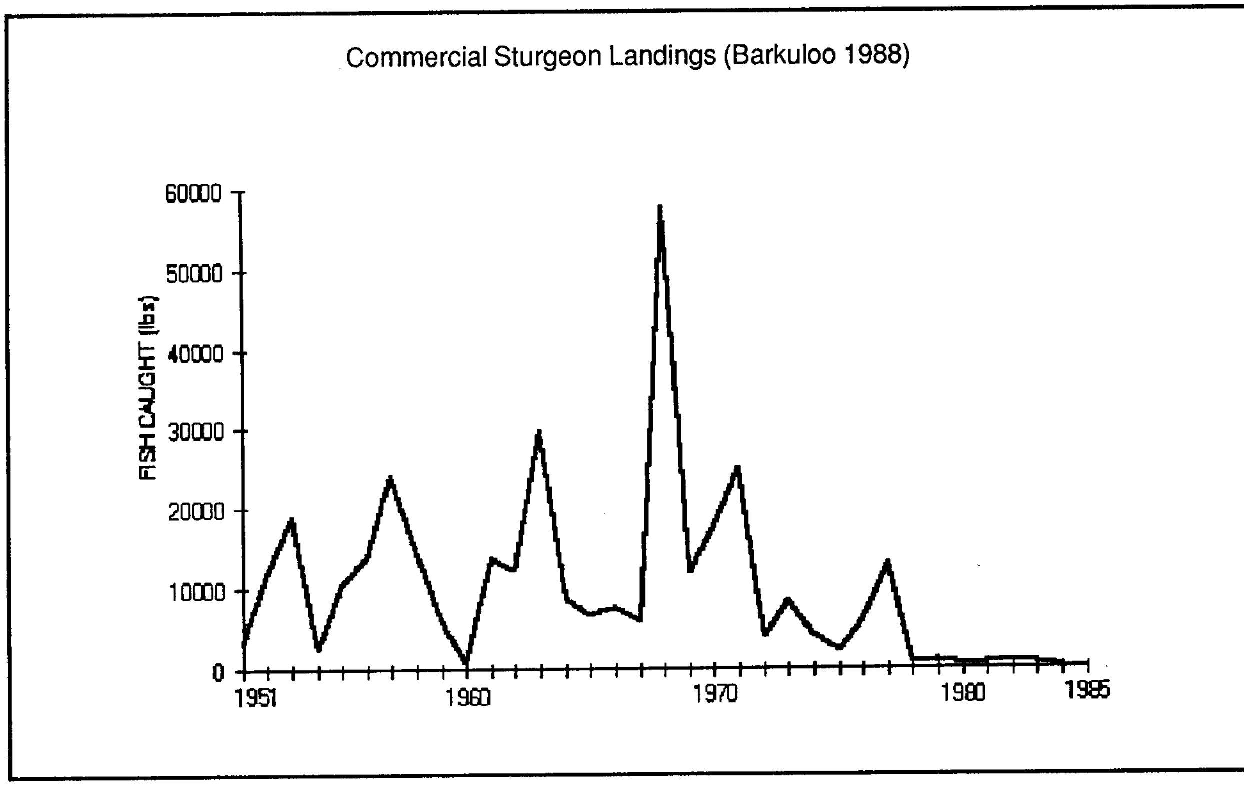


*Chart 1*

In September 1991, the Gulf sturgeon was officially listed as a threatened species on the Federal List of Endangered and Threatened Wildlife and Plants.

## Problem

### Rehabilitation Plan

Forty alternatives were examined for technical and economic feasibility that were contained under two fundamental considerations: (a) no action to be taken and (b) various combinations of replacing turbines, repair or replacement of other electrical equipment, and construction of a weir in the dam's tailwater to restore the original design head. The rec-

by the original design conditions, prior to welding the adjustable turbine blades into a fixed position (USACE 1993).

### Endangered Species Act Considerations

Section 7(a)(2) of the Endangered Species Act requires Federal agencies to ensure that activities they authorize, fund, or carry out are not likely to jeopardize the continued existence of any species listed on the Federal List or to destroy or adversely modify its critical habitat. If the action may affect a listed species or its critical habitat, the responsible Federal agency must prepare a Biological Assessment addressing the potential for impact to the species and

enter into consultation with the U.S. Fish and Wildlife Service.

Personnel from the U.S. Fish and Wildlife Service (USFWS) and the Florida Game and Fresh Water Fish Commission (FGFC) have indicated that the local currents and velocities within the tailrace may be factors in the distribution of the Gulf sturgeon immediately downstream of Jim Woodruff Dam. Rehabilitation of the powerhouse turbine units will result in operation of the units without spillage through the spillway gates a greater percentage of the time during lower flow months, the time of year when sturgeon utilize the tailrace area. Because rehabilitation of the powerhouse and replacement of the turbines could alter existing tailwater flow patterns immediately below the dam, the U.S. Army of Engineer District, Mobile, began informal consultation with the USFWS in the early phases of the rehabilitation study.

## Gulf Sturgeon Study

To assist in preparation of the Biological Assessment, information on the Gulf sturgeon was made available to Mobile District during several interagency information exchange meetings that included representatives of the USFWS, FGFC, and the National Marine Fisheries Service. The information included current habitat areas, habitat needs, and data collected by the USFWS during sturgeon population surveys conducted over a 10-year period. The data included each sturgeon's weight, length, sex, and, in most instances, the location where caught. The surveys were conducted in the late morning hours, during the months from May through October, typically in the tailrace or just downstream of the dam, with the use of a gill net. Chart 2 represents the total number of sturgeon caught, according to their size and location caught, for each year that the sturgeon sampling was conducted.

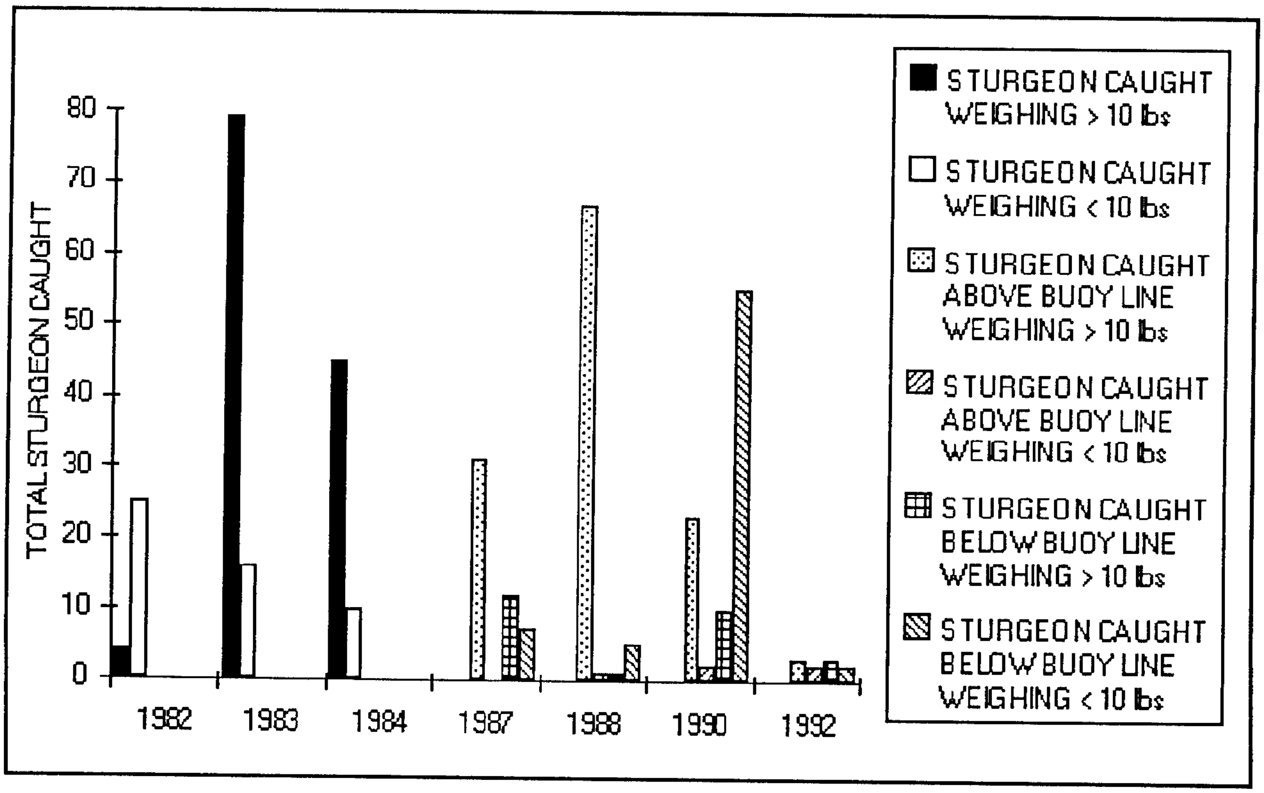


*Chart 2*

The "buoy line" as stated on Chart 2, refers to a tethered rope with buoys, located at the waters surface, approximately 600 ft downstream of the dam, which serves as the boundary marker for a prohibited boating area. During surveys from 1982 through 1984, the locations of the nets were not recorded by USFWS personnel. Evaluation of this data and further discussions with the USFWS, however, revealed that survey locations varied and several different collection techniques were used over the period of the surveys. Successful catches may have been dependent upon the specific sampling location or sampling technique. Therefore, only limited statistical analysis of relationships between the given data was determined to be possible.

In an attempt to identify the potential for impacts to the Gulf sturgeon because of the existing and predicted flow conditions, the sturgeon sampling data was compared with flow data and flow distribution data for existing and expected future conditions in the tailrace area. Characteristics of the flows discharged from Jim Woodruff Dam were obtained from log sheets transcribed at the dam and catalogued in a computer database and on microfilm at the District Water Management Section in Mobile. The log sheets contain hourly recorded values for the turbine discharge, spillway discharge, and total reservoir discharge. The particular spillway gate or gates open during the various flows were determined by referencing the dam's spillway gate opening schedule in use during each sturgeon population survey. Table 1 shows the number of fish caught for the various flow conditions at the dam, and notes whether the turbine blades were in their designed state (not welded) or in the welded

**Table 1**

| Reservoir Discharge Condition | Total Number of Fish Caught with Blades | | Number of Fish Caught per Survey | |
|---|---|---|---|---|
| | Welded | Not Welded | Welded | Not Welded |
| Turbine | 52 | 67 | 3.7 | 16.8 |
| Turbine and Lock | 11 | 28 | 5.5 | 9.3 |
| Turbine and Gate 7 | 0 | 57 | 0 | 7.1 |
| Turbine and Gate T2 | 103 | 0 | 5.7 | 0 |
| Turbine and Gates T2 and 7 | 1 | 0 | 0.5 | 0 |
| Turbine and Gates 7 and 8 | 0 | 1 | 0 | 1 |
| Turbine and Gates 7, 8, and 6 | 0 | 2 | 0 | 2 |
| Turbine and Gates T2, 7, and 8 | 0 | 5 | 0 | 5 |
| Turbine and Gates T2, 7, 8, 6, and 9 | 3 | 0 | 0 | 0 |
| Turbine and Gates T2, 7, 8, 6, 9, and 5 | 11 | 0 | 11 | 0 |
| Turbine, Lock and Gate 7 | 0 | 8 | 0 | 2.7 |
| Turbine, Lock and Gate T2 | 31 | 0 | 15.5 | 0 |
| Turbine, Lock and Gates T2 and 7 | 3 | 0 | 3 | 0 |
| Turbine, Lock and Gates 7 and 8 | 0 | 7 | 0 | 3.5 |
| Turbine, Lock and Gates T2, 7, 8, and 6 | 3 | 0 | 0 | 0 |

NOTE: All three units turbine blades were not welded from August 1981 to June 1987. Turbine blades were welded for unit 3 in June 1987, unit 1 in June 1988, and unit 2 in December 1988.

(fixed position) state. A summary of the flow conditions at Jim Woodruff Dam and the number of sturgeon caught for each day that a population survey was performed is contained in the Appendix.

During the low-flow months when the sturgeon utilize the tailrace area, the most common flow distribution condition is through the powerhouse with no spillage. A trend since 1987 is to also open the T-2 trash gate during generation to pass aquatic weeds and other debris through the dam. It appears from the above data that the largest numbers of sturgeon were collected under these two flow conditions. However, these data must be interpreted with caution, since this was the most common flow condition during sampling periods. The low number of sturgeon population surveys and lack of control over variables during the population surveys prevented the identification of a relationship between the type or rate of release from the reservoir and the occurrence or location of Gulf sturgeon immediately downstream of the dam. However, sturgeon were successfully collected during flow conditions, which are likely to be experienced a greater percentage of the time once rehabilitation of the units is completed (i.e., more flow directed through the powerhouse only or through the powerhouse with minimal spillage through the T-2 spillway gate).

## Summary

The original intent of this paper was to identify any relationship between the flow through the dam and the occurrence of sturgeon as reflected in the USFWS data. However, the lack of a standard procedure for the collection of data during the population surveys allowed only limited statistical analysis to be performed. As an alternative, characterization of the existing flow conditions while sturgeon were present in the tailwater area was performed. Because the rehabilitation alternative chosen will not significantly change the range of the existing flow conditions, and the study documented the apparent tolerance of the sturgeon during the existing and expected range of flow conditions, the Biological Assessment concluded with a determination that the rehabilitation project was unlikely to adversely impact the Gulf sturgeon or future USFWS sampling efforts. The USFWS concurred with the conclusion of the Biological Assessment. The proposed rehabilitation of the Jim Woodruff Dam powerhouse has been approved and is scheduled for funding in Fiscal Year 1995.

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# Appendix

| Date | Previous 24-hr discharge | Average 4-hr turbine discharge 9A-1P | Average 4-hr spill/lock discharge 9A-1P | Average 4-hr total reservoir discharge 9A-1P | Total sturgeon caught | Discharges by: |
|---|---|---|---|---|---|---|
| 08-Sep-82 | 11257 | 11304 | 0 | 11304 | 6 | P |
| 10-Sep-82 | 11970 | 12224 | 69 | 12293 | 20 | P, L |
| 21-Sep-82 | 12477 | 12400 | 0 | 12400 | 3 | P |
| 11-May-83 | 17375 | 17076 | 1238 | 18314 | 10 | P, S-7 |
| 12-May-83 | 19552 | 17840 | 3398 | 21238 | 1 | P, S-7, 8 |
| 17-May-83 | 17291 | 17680 | 0 | 17680 | 0 | P |
| 15-Jun-83 | 18452 | 16991 | 0 | 16991 | 9 | P |
| 22-Jun-83 | 15261 | 15627 | 0 | 15627 | 0 | P |
| 28-Jun-83 | 18477 | 17560 | 2046 | 19606 | 11 | P, S-7 |
| 06-Jul-83 | 19745 | 12080 | 5486 | 17566 | 2 | P, S-7, 8, 6 |
| 27-Jul-83 | 13712 | 11980 | 2139 | 14119 | 5 | P, L, S-7 |
| 29-Jul-83 | 13539 | 11340 | 485 | 11825 | 1 | P, L, S-7 |
| 13-Sep-83 | 11158 | 11290 | 0 | 11290 | 24 | P |
| 28-Sep-83 | 13114 | 5576 | 5937 | 11513 | 3 | P, L, S-7, 8 |
| 30-Sep-83 | 12024 | 11266 | 0 | 11266 | 13 | P |
| 21-Oct-83 | 13258 | 11100 | 2034 | 13134 | 6 | P, S-7 |
| 21-May-84 | 17650 | 17183 | 0 | 17183 | 2 | P |
| 04-Jun-84 | 19655 | 17968 | 2010 | 19978 | 8 | P, S-7 |
| 07-Jun-84 | 21462 | 17652 | 2040 | 19692 | 1 | P, S-7 |
| 14-Jun-84 | 14371 | 14464 | 0 | 14464 | 3 | P |
| 20-Jun-84 | 13763 | 10940 | 287 | 11227 | 2 | P, L |
| 27-Jun-84 | 11625 | 10756 | 1000 | 11756 | 9 | P, S-7 |
| 05-Jul-84 | 16446 | 10666 | 0 | 12556 | 5 | P, S-7 |
| 12-Jul-84 | 12156 | 10220 | 0 | 12270 | 7 | P, S-7 |
| 19-Jul-84 | 12624 | 11000 | 150 | 13160 | 2 | P, L, S-7 |
| 27-Jul-84 | 18833 | 17180 | 0 | 17180 | 5 | P |
| 22-Aug-84 | 22761 | 18580 | 196 | 22674 | 4 | P, L, S-7, 8 |
| 18-Sep-84 | 13968 | 14180 | 74 | 14180 | 6 | P, L |
| 27-Sep-84 | 9396 | 9720 | 0 | 9720 | 1 | P |
| 07-May-87 | 14938 | 10548 | 0 | 10548 | 1 | P |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10-Jun-87 | 16435 | 10718 | 4312 | 15030 | 5 | P, S-T2, 7, 8 |
| 24-Jun-87 | 24546 | 17118 | 7087 | 24205 | 3 | P, S-T2, 7, 8, 6, 9 |
| 30-Jun-87 | 30466 | 10440 | 18279 | 28719 | 3 | P, L, S-T2, 7, 8, 6 |
| 07-Jul-87 | 31208 | 19462 | 12126 | 31588 | 1 | P, S-T2, 7, 8, 6, 9, 5 |
| 15-Jul-87 | 17743 | 16956 | 0 | 16956 | 5 | P |
| 16-Jul-87 | 16972 | 17250 | 0 | 17250 | 0 | P |
| 22-Jul-87 | 15276 | 15130 | 0 | 15130 | 1 | P |
| 29-Jul-87 | 15557 | 15706 | 0 | 15706 | 0 | P |
| 21-Aug-87 | 11678 | 11732 | 500 | 12232 | 15 | P, S-T2 |
| 25-Aug-87 | 12255 | 11870 | 500 | 12370 | 2 | P, S-T2 |
| 03-Sep-87 | 12376 | 11868 | 500 | 12368 | 0 | P, S-T2 |
| 09-Sep-87 | 11841 | 11576 | 0 | 11576 | 6 | P |
| 14-Sep-87 | 12029 | 12026 | 0 | 12026 | 0 | P |
| 16-Sep-87 | 12017 | 12036 | 0 | 12036 | 7 | P |
| 24-Sep-87 | 10483 | 14016 | 0 | 14016 | 1 | P |
| 09-May-88 | 18366 | 7882 | 10769 | 18651 | 3 | P, L, S-T2, 7 |
| 12-May-88 | 19283 | 10437 | 8826 | 19263 | 1 | P, S-T2, 7 |
| 16-May-88 | 18290 | 10908 | 7450 | 18358 | 0 | P, S-T2, 7 |
| 18-May-88 | 16594 | 10238 | 5750 | 15988 | 2 | P, S-T2 |
| 23-May-88 | 16045 | 10234 | 5800 | 16034 | 3 | P, S-T2 |
| 02-Jun-88 | 10175 | 10176 | 0 | 10176 | 5 | P |
| 15-Jun-88 | 10126 | 10186 | 0 | 10186 | 0 | P |
| 27-Jun-88 | 7952 | 5450 | 2500 | 7950 | 2 | P, S-T2 |
| 07-Jul-88 | 6955 | 5458 | 1500 | 6958 | 2 | P, S-T2 |
| 15-Jul-88 | 6971 | 5452 | 1583 | 7035 | 16 | P, L, S-T2 |
| 25-Jul-88 | 6956 | 5454 | 1500 | 6954 | 3 | P, S-T2 |
| 27-Jul-88 | 6957 | 5458 | 1500 | 6958 | 3 | P, S-T2 |
| 03-Aug-88 | 5678 | 5462 | 0 | 5462 | 4 | P |
| 09-Aug-88 | 5494 | 5508 | 85 | 5593 | 0 | P, L |
| 17-Aug-88 | 5481 | 5460 | 85 | 5545 | 11 | P, L |
| 24-Aug-88 | 5484 | 5567 | 0 | 5567 | 1 | P |
| 31-Aug-88 | 5670 | 8332 | 0 | 8332 | 2 | P |
| 07-Sep-88 | 11041 | 6913 | 4051 | 10964 | 15 | P, L, S-T2 |
| 14-Sep-88 | 12323 | 10114 | 0 | 10113 | 1 | P |
| 08-May-90 | 18962 | 18012 | 1000 | 19012 | 1 | P, S-T2 |
| 30-May-90 | 19471 | 18506 | 1000 | 19506 | 7 | P, S-T2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 07-Jun-90 | 19415 | 18266 | 1000 | 19266 | 16 | P, S-T2 |
| 19-Jun-90 | 16440 | 1000 | 15382 | 16382 | 10 | P, S-T2, 7, 8, 6, 9, 5 |
| 27-Jun-90 | 17882 | 13936 | 400 | 14336 | 22 | P, S-T2 |
| 10-Jul-90 | 12728 | 12746 | 0 | 12746 | 9 | P |
| 17-Jul-90 | 9557 | 5217 | 4312 | 9529 | 8 | P, S-T2 |
| 27-Jul-90 | 7955 | 4928 | 3000 | 7928 | 3 | P, S-T2 |
| 08-Aug-90 | 8984 | 5009 | 4000 | 9009 | 9 | P, S-T2 |
| 30-Aug-90 | 8399 | 4899 | 3611 | 8510 | 4 | P, S-T2 |
| 21-Sep-90 | 7852 | 4953 | 2656 | 7609 | 1 | P, S-T2 |
| 12-Aug-92 | 8751 | 8694 | 0 | 8694 | 10 | P |

NOTE: In "Discharges by:" column, P represents powerhouse, L = lock, S-T2 = spillway trash gate 2, numbers 5 through 9 = spillway gates.

# Water Quality Changes in the Savannah Harbor Following Modifications

*by*
*Diane K. Hampton*[1]

## History of the Savannah Harbor

The Savannah Harbor has a rich history with many changes that have affected the location of the saltwater-freshwater interface over the years starting officially in the late 1800s. The area just north and east of the Harbor was designated as a National Wildlife Refuge in 1927. Through the years, this refuge has grown to over 26,500 acres. The Harbor itself is heavily industrialized with paper mills, a sugar refinery, many chemical factories, and docking facilities. The riverfront area of Savannah is a tourist attraction rich in historic architecture with many shops and restaurants. The industrial, navigational, tourism, and wildlife interests are often found competing against one another for this multipurpose resource.

## Location

The Savannah Harbor is located on the South Atlantic Coast, 75 miles south of Charleston Harbor, South Carolina, and 120 miles north of Jacksonville, FL. The Harbor comprises the lower 21.3 miles of the Savannah River that, with some of its tributaries, forms the boundary between South Carolina and Georgia. The dredged channel extends 11.4 miles across the bar to the Atlantic Ocean (U.S. Army Corps of Engineers 1992).

From the U.S. Highway 17 (Houlihan) Bridge to the Dixie Crystals Sugar Refinery, the river consists of three waterways: Front River on the South, Middle River and Little Back River on the North. Middle River rejoins Front River opposite the sugar refinery. Little Back River becomes Back River and continues parallel to Front River to their confluence near Fort Jackson, just east of the city. Onslow Island lies between Front River and Middle River. Hutchinson Island lies between Front and Back rivers. Approximately 1.5 miles seaward of the junction of Back and Front rivers, they split again into the North and South channels, and remain so until their confluence with the Atlantic Ocean. Elba Island lies between the North and South channels. The North Channel is the navigation channel for shipping vessels (See Figure 1).

## Chronology of Corps of Engineers Projects on the Harbor

The existing project was originally authorized by the Act of June 23, 1874, and was modified by subsequent acts. In June of 1910, a 26-ft-deep channel from Fort Pulaski to the Seaboard Coast Line Railroad Bridge was authorized. In July of 1912, this channel was extended by adding a 21-ft channel from the Seaboard Coast Line Railroad Bridge to the foot of Kings Island at river mile 18. In August of 1917, a 30-ft-deep channel from Fort Pulaski to the sea was authorized. Further deepening and harbor extensions were authorized in 1927, 1930, 1935, 1945, 1946, 1954, 1962, 1965, 1976, 1984, 1989, 1992, and 1993 (U.S. Army Corps of Engineers 1991).

In 1977, the Tide Gate, New Cut, and Sediment Basin were constructed in Back River as a cost-saving project for maintenance dredging. It saved one million dollars per year while it was in use from 1978 to 1991. The gates opened on flood tide and closed on ebb tide, forcing the water through New Cut and down

[1] U.S. Army Engineer District, Savannah; Savannah, GA.

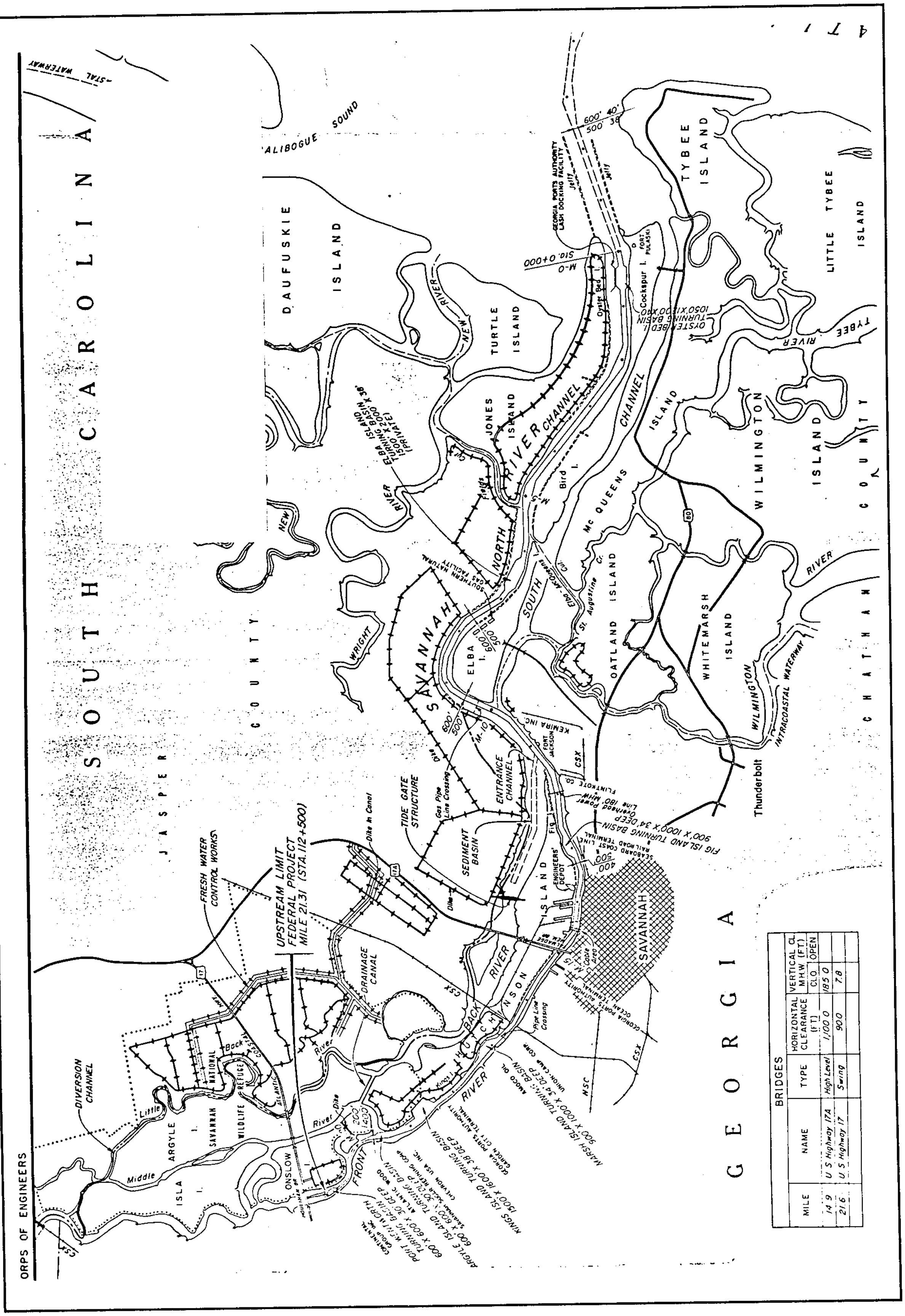


*Figure 1. Savannah Harbor*

Front River at high velocities, preventing sediment from falling out in Front River where it is most costly to dredge because of the distance to disposal areas. The cost benefits as well as the navigational safety of not having dredges and pipelines in the channel made the Tide Gate one of the most popular Corps projects of Savannah District's history. The project was designed such that the sediment fell out in the Sediment Basin where Back River meets Front River. It is much less expensive to dredge the Sediment Basin since the disposal areas are adjacent to the Basin. The project was taken out of operation and New Cut was filled in 1991.

The current channel geometry consists of a 38-ft-deep channel from stations 0+000 to 102+000 and a 36-ft-deep channel from 102+000 to 112+500. The 1993 Deepening project authorized a 44-ft channel from stations -60+000 to -14+000 and a 42-ft channel from stations -14+000 to 0+000. It also authorized a channel 42 ft deep from 0+000 to 24+000, a 44-ft-deep channel from 46+000 to 79+600, a 42-ft channel from 79+600 to 103+000, and a 38-ft-deep channel from 103+000 to 104+250 (U.S. Army Corps of Engineers 1992).

## Reason for the Harbor Modifications

New Cut, which was constructed as a throughway for the water backed up by the Tide Gate, was filled in 1991 and the Tide Gate had all of its gates held open. The U.S. Fish and Wildlife Service and State Resource agencies required that this channel modification be made in order for the Savannah Harbor Deepening Project to be approved. Closing New Cut and opening the tide gate restored the navigation project back to pre-1975 conditions except for deepening and widening. Closing the cut prevents striped bass eggs from floating through the cut on ebb tide to Front River where they are exposed to higher pollutant concentrations. Prior to the closure, eggs could have been forced through the cut at ebb tide and flushed seaward to higher salinity concentrations where they do not survive.

The optimum salinity concentration for the striped bass eggs to thrive is about 1 to 3 parts per thousand (ppt) (Dudley and Black 1978). Eggs that are forced into the higher salinity concentrations of 10 to 20 ppt do not survive as well as those allowed to remain in lower salinity concentrations.

Little Back River, now with lower salinity concentrations, provides a safe haven for striped bass eggs except for periods of high flow, where they can be flushed into the lower reaches of the Savannah River where salinity concentrations are greater than 20 ppt.

Another reason for the channel modification was to restore saltwater marsh back to freshwater marsh. When the tide gate was operating, about 4,000 acres of freshwater marsh in the National Wildlife Refuge were gradually converted to saltwater marsh. Now that the gate has been opened, these acres are now converting back to freshwater marsh. Since there is a shortage of freshwater marsh in the United States, it is much more valuable than saltwater marsh; this conversion is welcomed by the U.S. Fish and Wildlife Service (Pearlstine et al. 1989).

## Water Quality Conditions Before and After Modifications

The saltwater-freshwater interface location can be summarized according to Table 1. The locations of the salinity interfaces are shown on Figures 2-7.

**Table 1**
**Comparison of Location of Salinity Interface Before and After Harbor Modifications**

| Flow, cfs | | Location, River Mile | |
|---|---|---|---|
| | | Front River | Back River |
| 7,000 | Before | 24.5 | 23.5 |
| | After | 23.0 | 20.0 |
| | Difference | 1.5 | 3.5 |
| 9,000 | Before | 23.5 | 22.5 |
| | After | 22.0 | 16.0 |
| | Difference | 1.5 | 6.5 |
| 15,500 | Before | 19.5 | 18.0 |
| | After | 18.2 | 13.5 |
| | Difference | 1.3 | 4.5 |

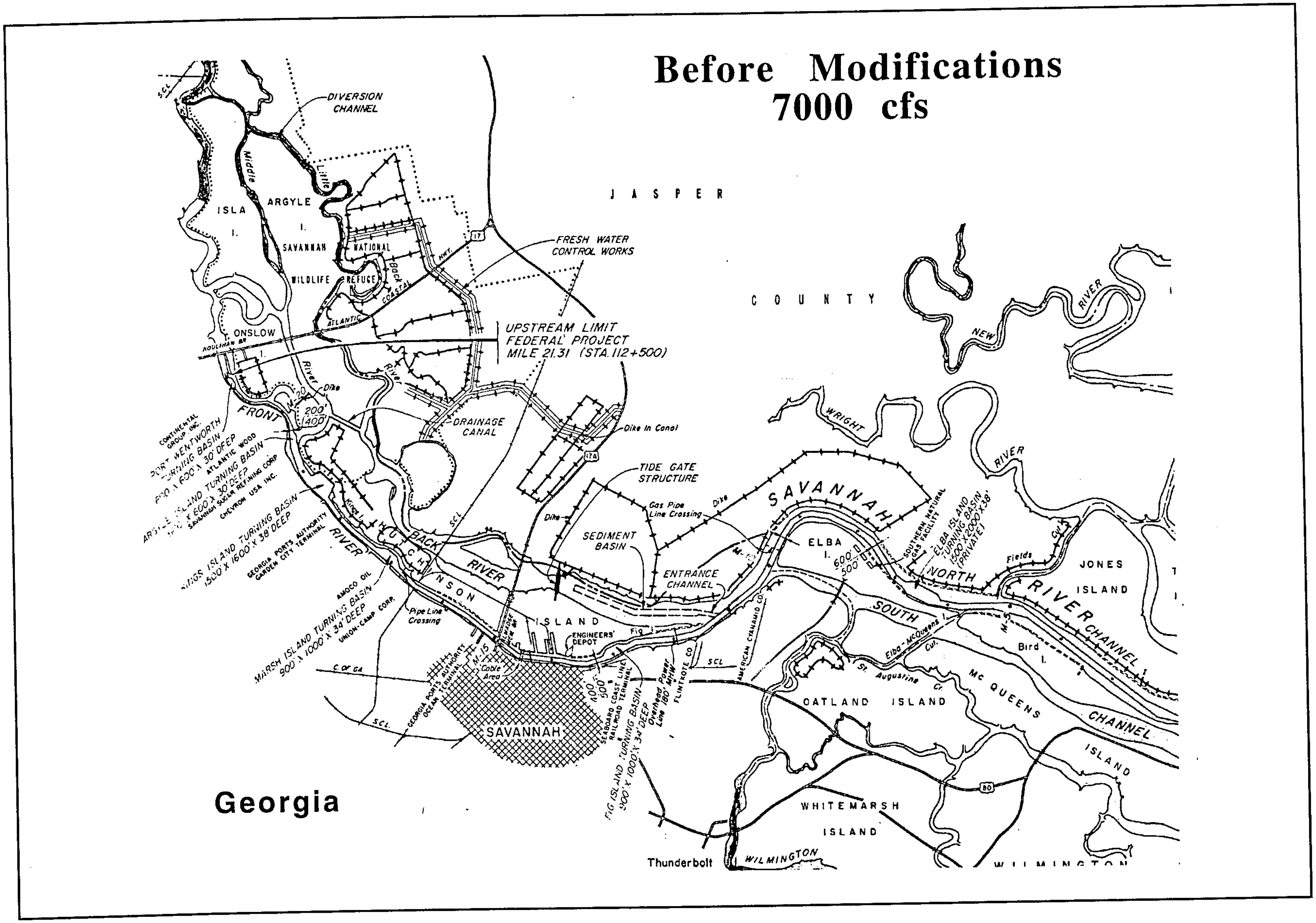


*Figure 2. Salinity interface before modifications, 7,000-cfs flow*

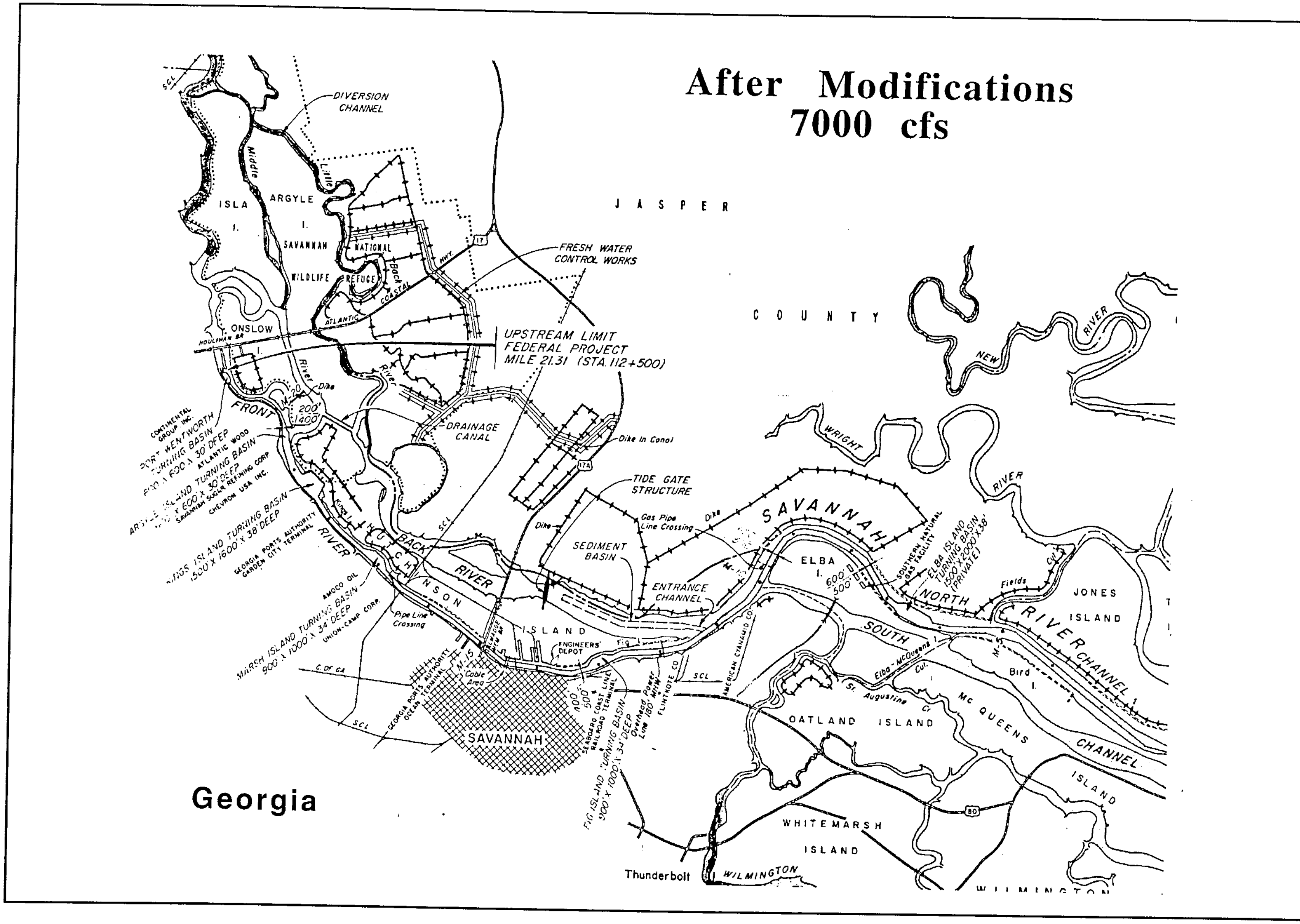


*Figure 3. Salinity interface after modifications, 7,000-cfs flow*

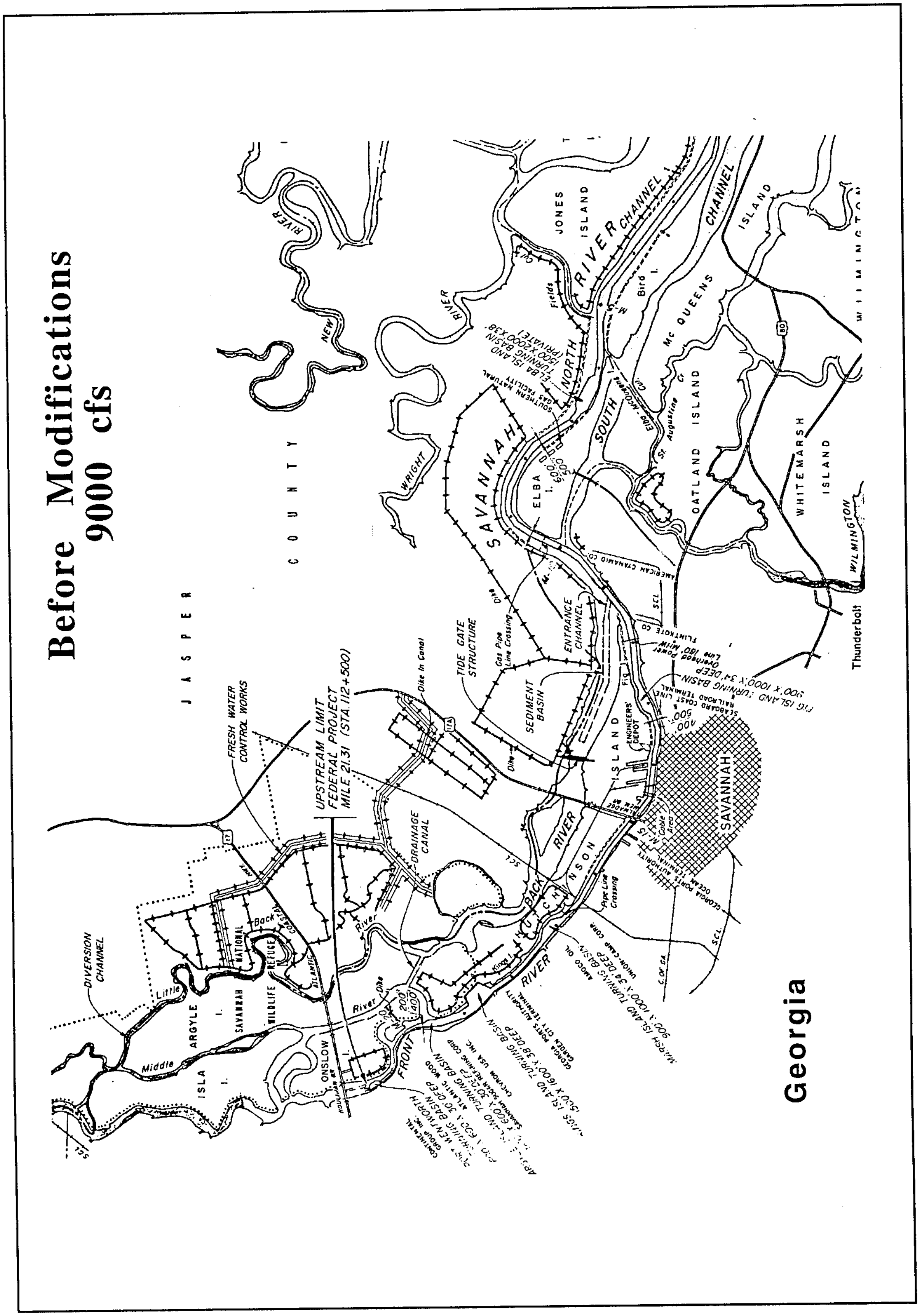


*Figure 4. Salinity interface before modifications, 9,000-cfs flow*

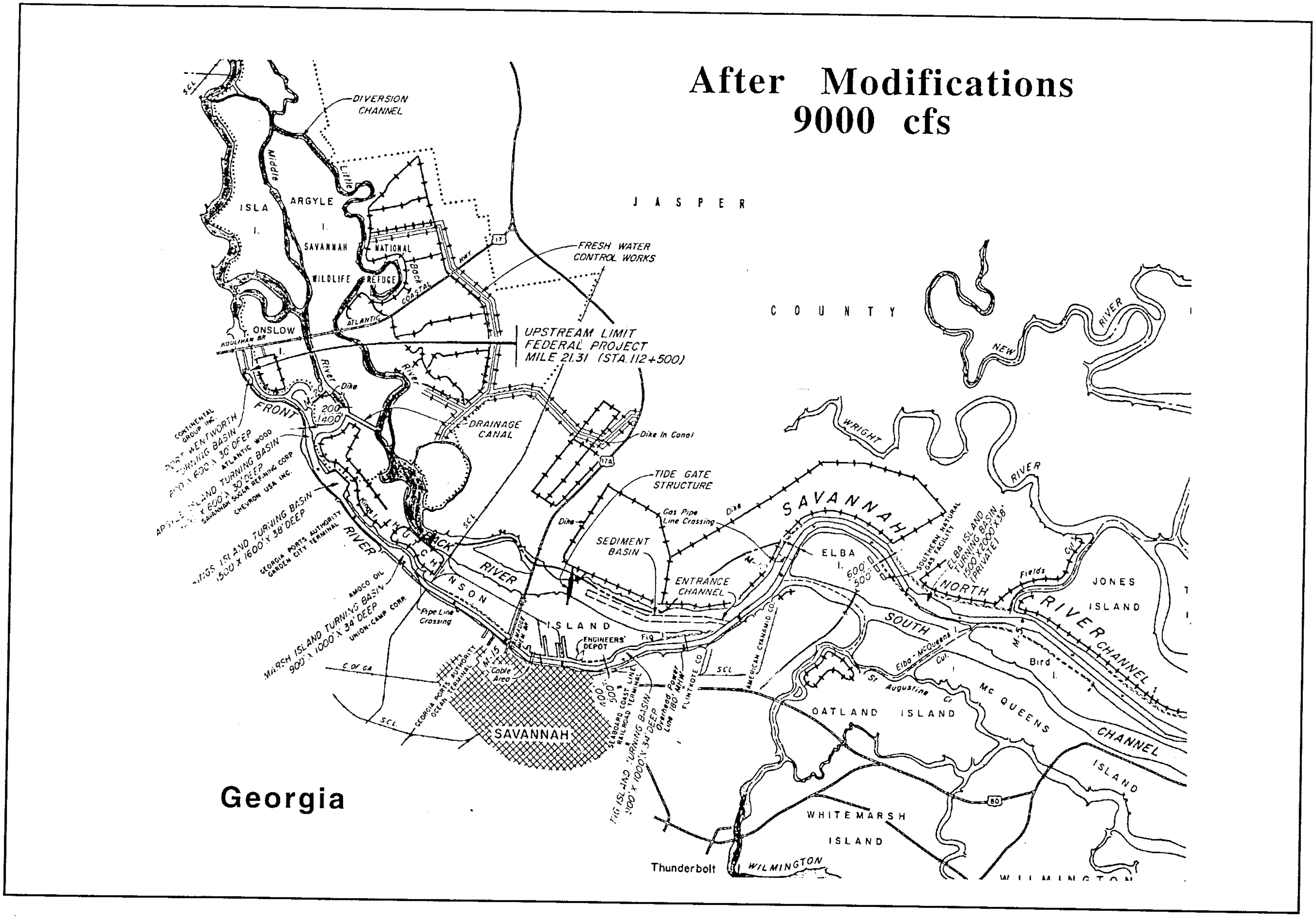


**Figure 5. Salinity interface after modifications, 9,000-cfs flow**

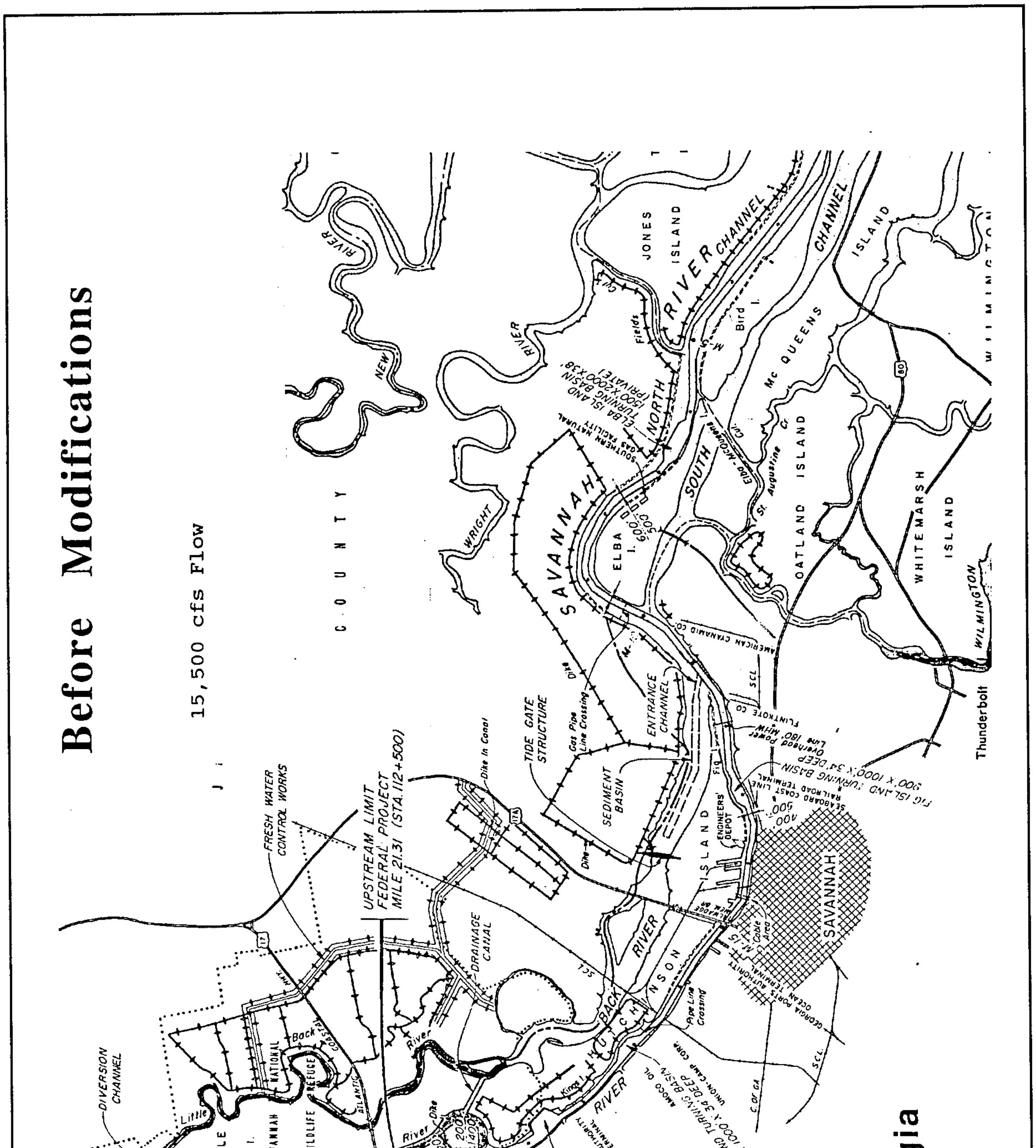


*Figure 6. Salinity interface before modifications, 15,500-cfs flow*

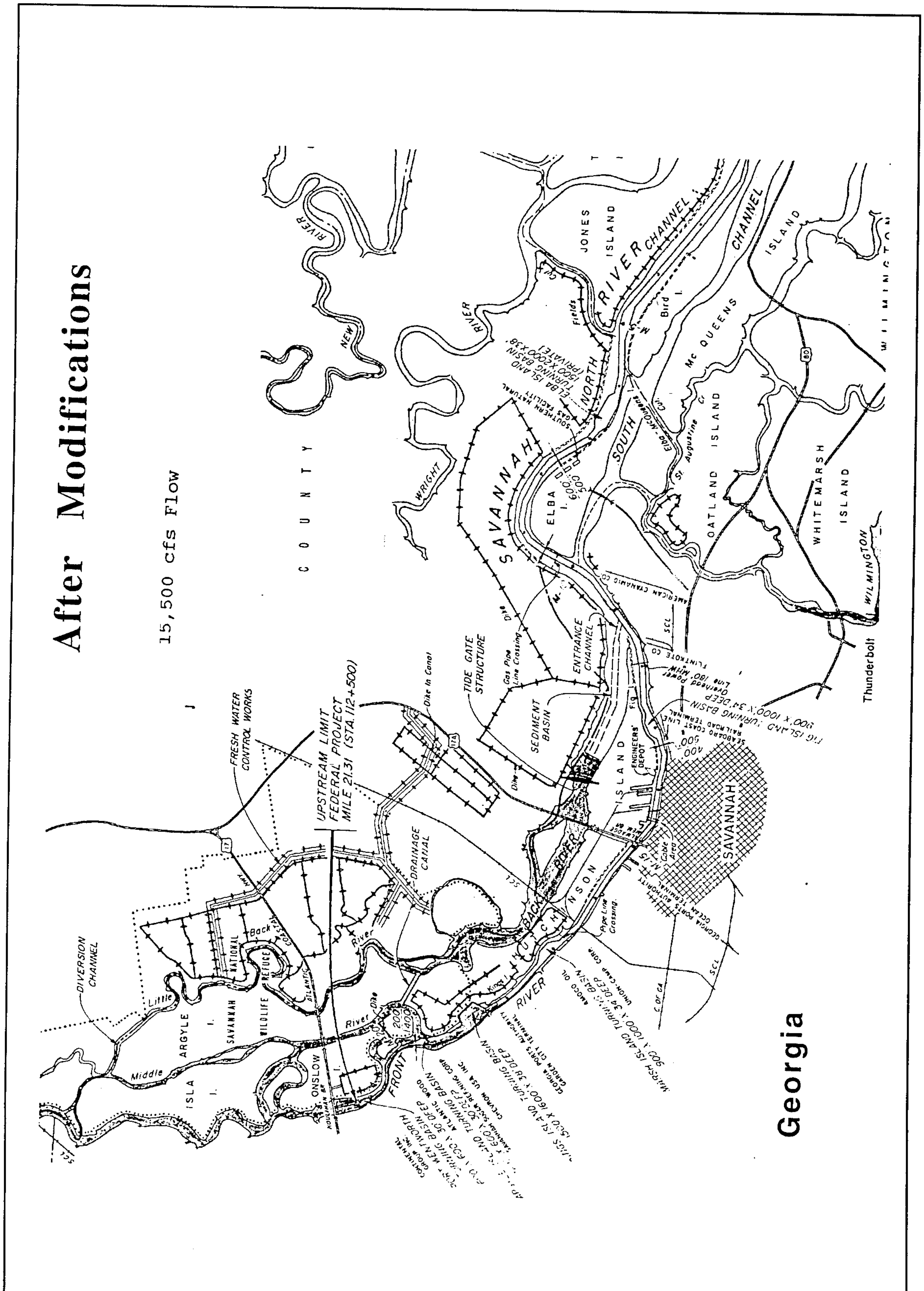


*Figure 7. Salinity interface after modifications, 15,500-cfs flow*

The modifications have had a significant change on the location of the saltwater-freshwater interface. The most notable change has occurred in Back River adjacent to the Savannah National Wildlife Refuge. Wildlife refuge personnel have noted that many acres of saltwater marsh vegetation are being replaced with freshwater vegetation. The locations found in the table were computed from actual field data that were used in "Curvefit," a computer program written by the U.S. Army Engineer Waterways Experiment Station. The polynomial of 1 deg (straight line) was chosen as the best and most logical curve for the data. The curves are shown on Figures 8-11. The data were taken at mid-depth using a hydrolab water quality instrument (or a YSI salinity meter in earlier years) for the location where salinity was 0.5 ppt. Data were collected over a 15-year period at various tides and river flow rates. The nearest flow gauge is at Clyo, and it was used for the flow rate parameter. Tide, wind, and flow have significant effects on location of the interface. Flow has more of a direct effect on salinity location. When fit with a curve with the Curvefit program, the flow versus river mile curves correlated better than tide versus river mile. The flow rates 7,000, 9,000, and 15,500 cfs were chosen for the table because of their exceedence probabilities. The flow rate 9,000 cfs is the average flow (or has a 50-percent chance of exceedence) for the period of record used, which is the time that the Savannah River has been under regulation of Thurmond Dam since 1954. The flow rate 7,000-cfs will be exceeded 80 percent of the time, and 15,500 cfs will be exceeded 20 percent of the time. At the lowest chosen flow for plotting (7,000 cfs), it can be seen that the salinity interface is kept well downstream of U.S. Highway 17, and this occurs at least 80 percent of the time. Prior to the modifications, the salinity interface was well upstream of the highway for the 7,000-cfs flow and within less than 0.5 miles of the freshwater intake for the impounded areas of the National Wildlife Refuge.

## Future Plans

The Savannah Harbor continuously undergoes changes for navigation. The near future of the Harbor may entail extending the deepened channel upstream of U.S. Highway 17 (river mile 21.58). The salinity interface will most likely change its location to further upstream, but its location cannot be estimated without a model study incorporating the proposed channel geometry. There is a significant amount of environmental opposition to further development of the Harbor. If approved model studies can show that salinity changes will be insignificant, then such opposition should be eliminated or reduced. A model study using a three-dimensional finite element model will best illustrate the effect of deepening and extension because of the vast areas of marsh that undergo wetting and drying; however, such models are costly and funding is limited.

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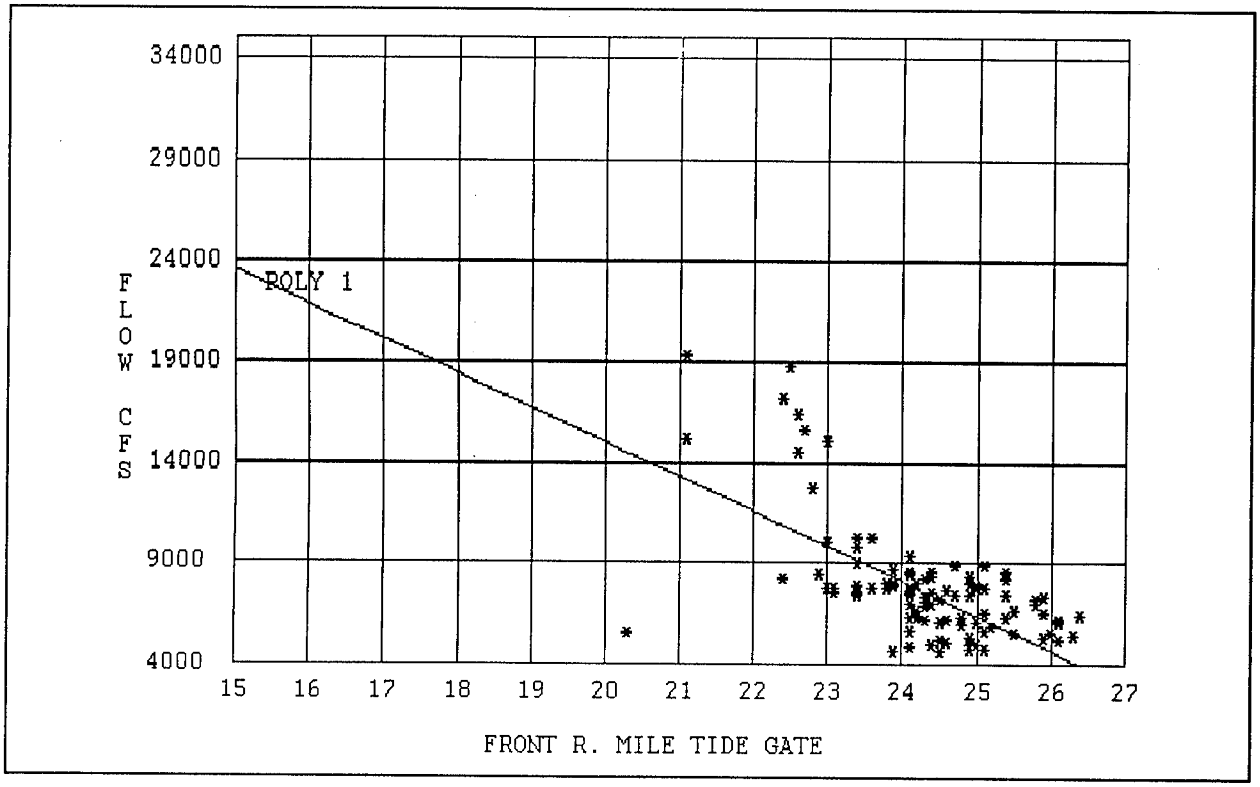


*Figure 8. Salinity interface before modifications, Front River*

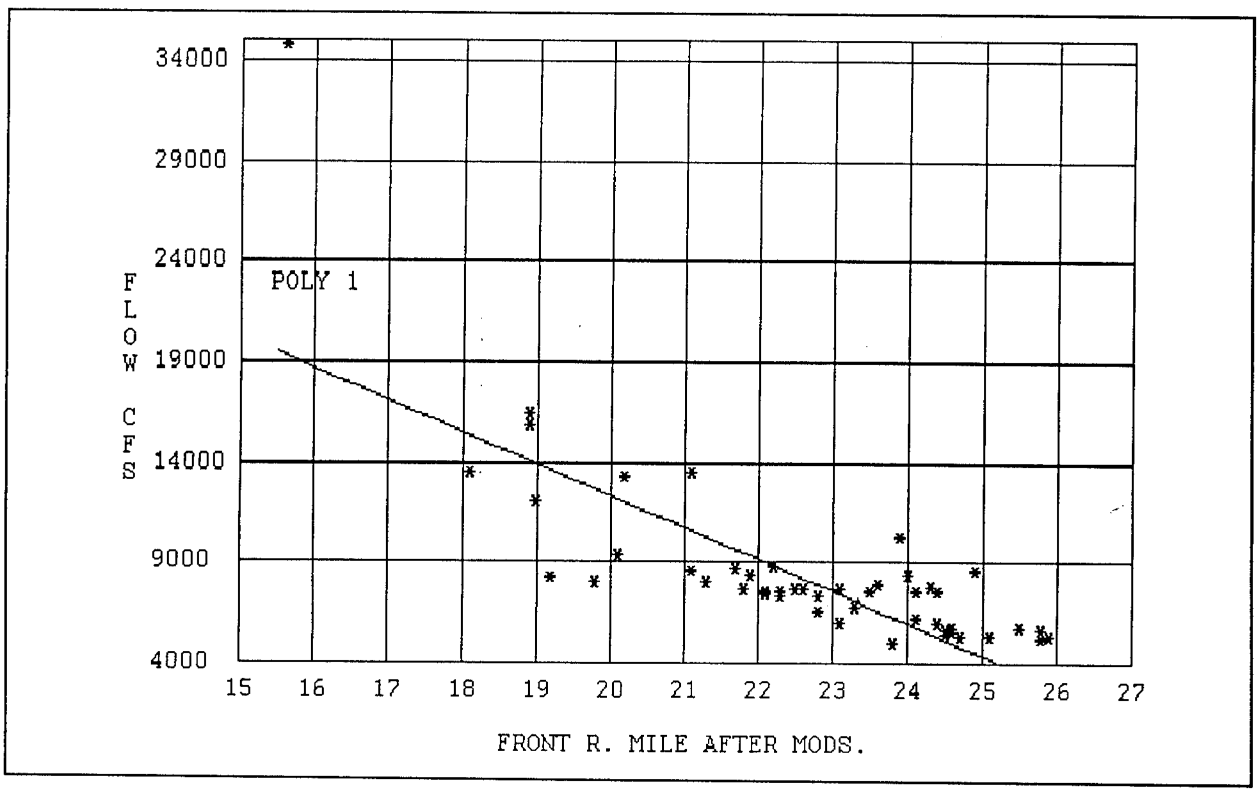


*Figure 9. Salinity interface after modifications, Front River*

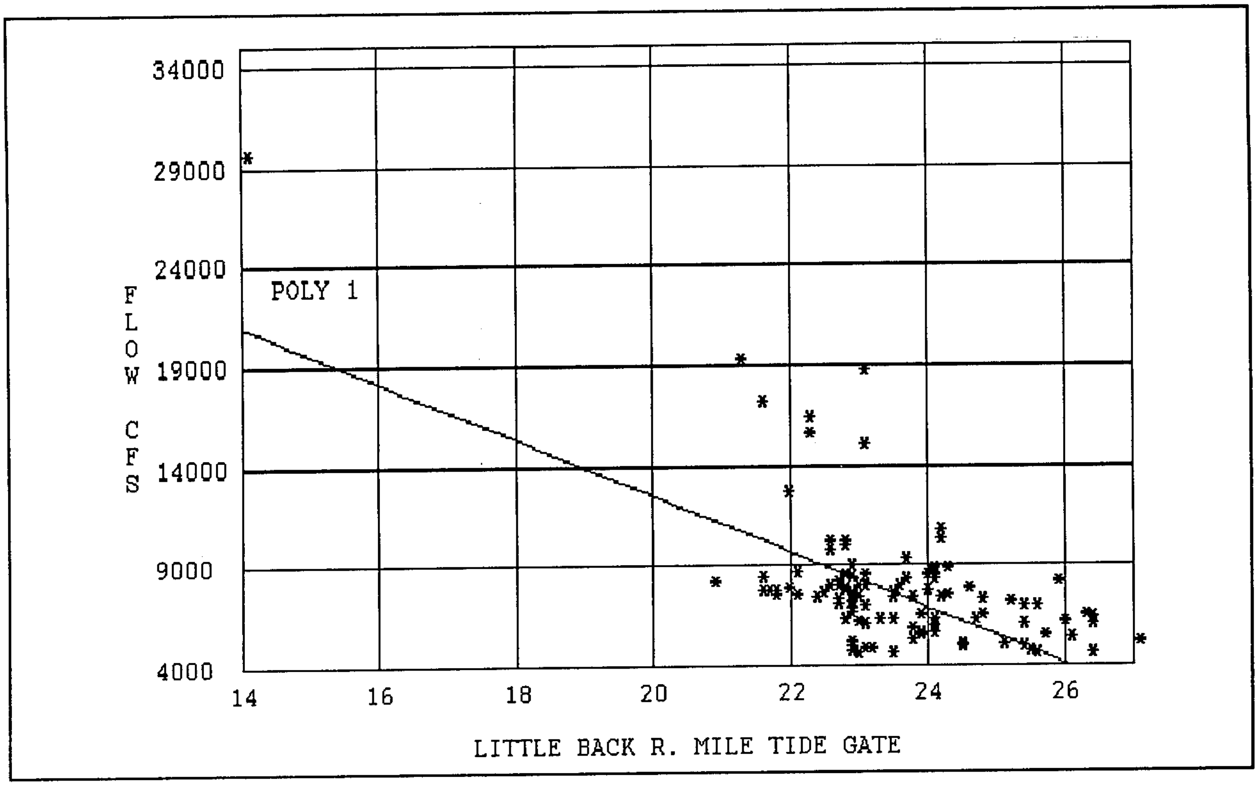


*Figure 10. Salinity interface before modifications, Back River*

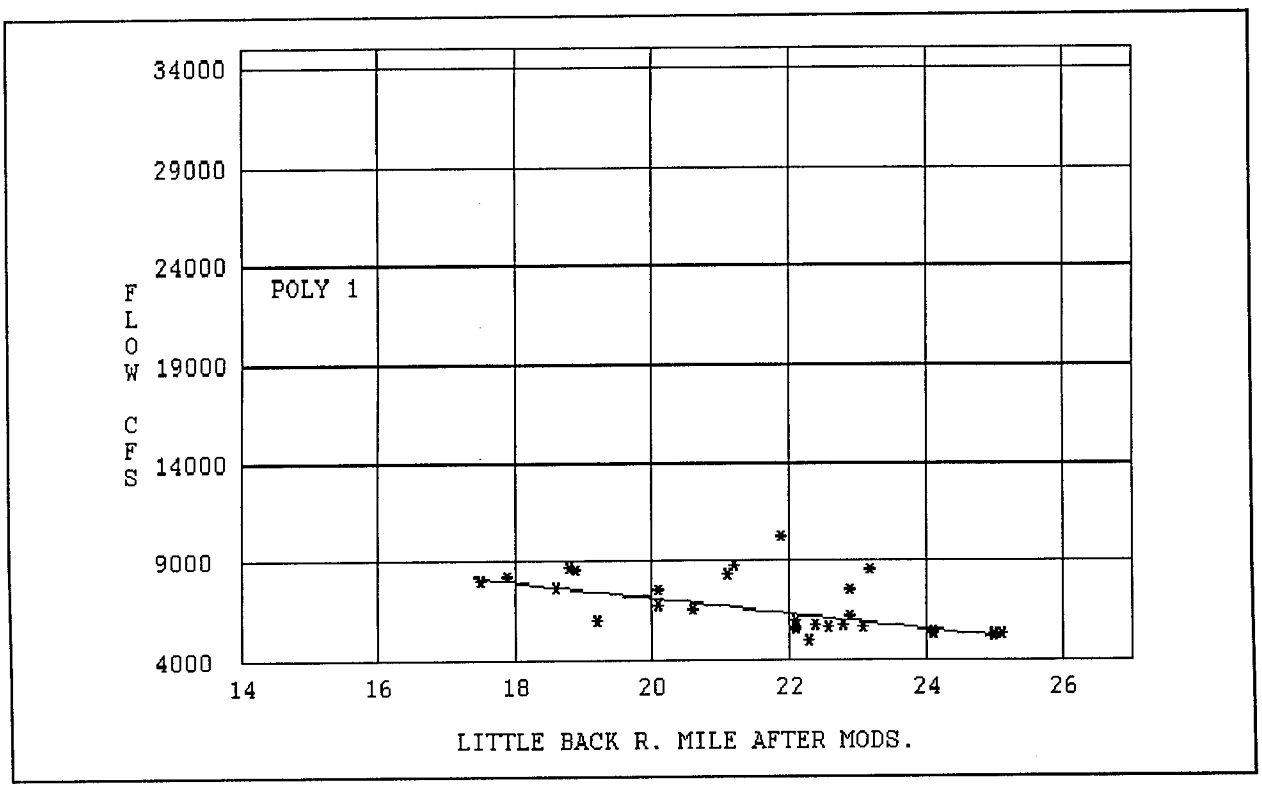


*Figure 11. Salinity interface after modifications, Back River*

# Lower Savannah River Environmental Restoration Study


*by*
*Monica Simon Dodd*[1]


## Introduction

Congress has authorized several projects along the Lower Savannah River, including the existing navigation project that was authorized by the Rivers and Harbors Act of March 3, 1881. This paper (excerpts are taken from a reconnaissance report) reviews the problems and opportunities of the Lower Savannah River basin and makes recommendations for environmental restoration.

## Background

The Savannah River forms the boundary between the States of Georgia and South Carolina. The authorized navigation project for the Savannah River between Augusta and Savannah, GA, provides for a navigation channel 9 ft deep and 90 ft wide from the upper end of Savannah Harbor to the head of navigation at Augusta just above the 13th Street bridge, a distance of 180.85 miles. This navigation project is known as the Savannah River Below Augusta Project. The overall Lower Savannah River Environmental Restoration study is concentrating on the Lower Savannah River, which includes the Savannah River and surrounding wetlands from the vicinity of Augusta, GA, to the upper end of the Savannah Harbor. However, we anticipate that this will be the first of several projects that will be generated from the Lower Savannah River study. This particular study concentrates on the area surrounding cutoff bend No. 3 (Hickory Bend) and cutoff bend No. 4 (Flat Ditch Point), located at river miles 40.9 and 41.3, respectively.

The Lower Savannah River Basin provides a home for at least nine threatened and endangered species. Equally important, there are at least 10 candidate species in this area. Candidate species are those currently being reviewed for possible addition to the Endangered and Threatened Species List under the Endangered Species Act of 1973, as amended. Restoration of fish and wildlife habitat by improving flow through the wetlands improves water quality and fish and wildlife habitation. Thus, it could be possible to prevent some of the candidate species from becoming threatened or even endangered species.

## Study Purpose and Scope

As stated above, excerpts of this paper were taken from a reconnaissance report. The reconnaissance report is conducted as part of the two-phase process, the reconnaissance phase and the feasibility phase. The reconnaissance phase investigates the problem(s) and studies potential solutions that appear to be economically feasible and environmentally acceptable.

The feasibility phase concentrates on those activities such as modeling, surveys, and detailed evaluations that will be conducted. At the time this paper is being written, we are currently in the midst of the feasibility phase. Modeling used in this feasibility phase includes both environmental and hydraulic modeling.


[1] U.S. Army Engineer District, Savannah; Savannah, GA.

The study purpose is to determine if any modifications should be made to the cutoffs and other structures constructed as part of the Savannah River Below Augusta Project in order to environmentally restore the Lower Savannah River and surrounding wetlands and enhance fish and wildlife habitat and water quality. The reconnaissance phase included (a) formulating and evaluating alternatives to determine if restoration measures could be accomplished by increasing flow throughout some of the cutoff bends and oxbows; (b) evaluating various related problems and defining potential solutions; (c) determining if there is a Federal interest in the implementation of solutions; and, (d) determining whether the planning should proceed into the next planning phase (feasibility phase).

Along the Lower Savannah River, there are 40 cutoff bends and oxbows. Of these 40, this study originally selected 12 for analysis, which were refined down to 2, cutoff bend No. 3 (Hickory Bend) and cutoff bend No. 4 (Flat Ditch Point), as mentioned above.

The Savannah National Wildlife Refuge, which is in the lower portion of the study area, includes over 26,000 acres of hardwood swamp, freshwater marsh, impoundments, and estuarine marsh. All of this area benefits by improving flow through cutoff bends No. 3 and No. 4 because this water ultimately filters down into the refuge and provides important habitat for wintering waterfowl, wading birds, and endangered species. Development and recent weather patterns have impacted the refuge through reduced runoff and lower water levels. If such conditions occur during critical nesting or spawning times, some species may be severely impacted.

## Problem Identification

### Objectives

In response to the Congressional resolution authorizing the reconnaissance study, the objectives of this study focused on restoring the environment of the Lower Savannah River and the surrounding wetlands and improving fish and wildlife habitat.

The following objectives were developed for this study:

*a.* Restoration of spawning habitat for important fisheries.

*b.* Restoration of flow to freshwater wetlands.

*c.* Restoration of overall environmental quality of the Lower Savannah River, while maintaining navigability.

### Problems and Opportunities

Water resources-related problems were identified, and several visits were made to the study area to survey the navigation project and discuss any problems and concerns that the resource agencies may have. As a result of these efforts, the following specific problems and opportunities were identified:

*a.* Habitat degradation.

*b.* Water quality.

*c.* Flow regime.

*d.* Access.

### Feasibility Phase Models

The habitat evaluation model being used for the Lower Savannah River project is a modified version of the U.S. Fish and Wildlife Service's Habitat Evaluation Procedure (HEP). The modified version being utilized is focused on the warmwater aquatic community. The parameters that are being studied include dissolved oxygen, pH, temperature, percent cover, percent pools, and water velocity. The model approach is community based instead of the traditional HEP model species-based approach.

Outcome of the model is a value known as Habitat Units (HU). The habitat units that can be achieved through the various project

alternatives will be compared with the price of the different alternatives to get an HU per dollar spent ratio much like a traditional cost/ benefit ratio. No money terms will be used in the HU values, only benefits to the environment. This model allows decision makers to identify the project alternative that maximizes environmental benefits for the dollars spent.

TABS-2 is a two-dimensional numerical model that can be used to predict hydraulic behavior and sediment transport in a riverine environment. The model uses existing topographic and hydrographic contours and surface roughness characteristics to approximate specific conditions. Upstream and downstream boundary conditions are used to calibrate the model for a range of flows. After the existing conditions are modeled and calibrated, modifications to the waterway can be modeled to determine the hydraulic response. TABS-2 will graphically illustrate velocities, direction of flow, and water surface profiles. Knowledge of material types and velocities can be used to predict sediment transport.

## Formulation of Alternatives

### Types of Improvement Alternatives

After identifying the two cutoff bends for detailed investigations, to be proposed, actions were suggested for each cutoff bend. Complete closure and partial closure of cuts No. 3 and No. 4 will be studied.

### Alternatives to Improve Water Quality and Habitat Degradation

Full restoration of all navigational cuts was not considered for several reasons: (a) the impact such restoration would have on navigation; (b) the cost associated with full restoration is high; and (c) full restoration may actually result in a loss of habitat for fisheries. Many of the oxbows provide significant benthic habitat for fish species. Full restoration would, in some cases, result in a negative impact to these resources by creating additional mainstream habitat at the expense of still-water habitat.

Cut No. 3 has been proposed for closure in an attempt to improve water quality in Bear Creek and, therefore, in Abercorn Creek, where the city of Savannah's water intake facility is located. Additionally, Bear Creek flows through significant palustrine forested wetlands. Increased flow to this creek would result in hydrologic improvements to this wetland system.

Likewise, closure of Cut No. 4 would result in increased contact between the river and associated wetlands. As this cut is quite long and has significant sedimentation problems, closure was determined to be the best option.

### Method of Total Closure

Two methods of total closure were analyzed. The first involved total closure of an existing cut by use of a permanent diversion structure accompanied by dredging a pilot channel. There would be no impact on navigation with this method of closure.

The second method involved total closure of the existing cut by use of a diversion structure only; no dredging of a pilot channel would be performed. This option would take additional time, but would result in the least amount of potential environmental damage resulting from dredging and disposal. Also, as the cut would not be completely closed off from the reopened channel, additional oxbow habitat would be created to replace that which is lost during cut closure. However, if this second method of closure is used, deauthorization or modification/relocation of the authorized navigation channel would be reviewed in the feasibility phase.

### Alternatives to Improve Flow Regime

This study did not examine means to improve the overall flow regime of the Savannah River. Instead, it examined improving the local flow regime in the vicinity of each

site by diverting flow through the cutoff bends. Altering the current flow regime has many potential benefits for fish and wildlife and for recreation in the lower river. However, these factors must be balanced with upstream needs and are beyond the scope of this report, which includes only restoration of flow throughout the Lower Savannah River.

## Findings and Conclusions

Based on the results of the reconnaissance study, the following findings and conclusions were developed.

- When navigation cuts were constructed, a large segment of the river (approximately 13 percent) was removed from contact with the main river channel, especially during low flow.
- The cutoff bends have accumulated large amounts of organic materials, leading to reduced dissolved oxygen levels during low flow and warmwater conditions.
- The accumulation of organic materials negatively impacts fish recruitment and available habitat.
- Impacts to Bear Creek, Mill Creek, and associated wetlands have occurred because of construction of navigation cuts and maintenance of the main river channel. Flow to Bear Creek has been impacted by construction of cut No. 3. Mill Creek has been impacted by the construction of cut No. 4 and by blockage from sediments.
- All of the above factors reduce the duration and depth of flooding in the upper portion of the Savannah National Wildlife Refuge and privately owned wetlands. Therefore, flushing of detritus and nutrients from these wetlands is reduced.
- There appears to be feasible alternatives to restore the environment.
- There is a Federal interest in restoring fish and wildlife habitats that existed in the cutoff bends of the Lower Savannah River and surrounding wetlands before they were cut off by the Federal Navigation Project and in enhancing the water quality. Therefore, the reconnaissance phase was certified, and the Savannah District has forged ahead into the feasibility phase.

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# Verification Considerations in the Galveston Bay Three-Dimensional Numerical Modeling Study

*by*
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## Background

Galveston Bay, Texas, (Figure 1) is the largest and most productive estuary on the Texas Gulf coast. It is wide and shallow, predominately less than 6 ft deep, and is incised by a 40-ft-deep, 400-ft-wide navigation channel. Mean diurnal tide range is 1.4 ft, and freshwater inflow from its several tributaries averages about 13,000 cfs. Mixing conditions range from partly to well mixed, with winds significantly affecting both circulation and mixing processes.

The purpose of the modeling effort is to predict the salinity and circulation impacts of enlarging the channel by 10 ft in depth and 200 ft in width in two stages. Salinity and circulation changes will be evaluated directly and by the output of an oyster production model that uses the hydrodynamic and salinity results as input data. To meet study objectives, the model must faithfully reproduce the long-term behavior of the estuary.

## Model

The geometric complexity of this estuary, with its navigation channel, multiple inlets, and many proposed disposal islands, requires a numerical model that relies upon an unstructured computational mesh. The code chosen was the finite element model RMA10-WES, which is a U.S. Army Engineer Waterways Experiment Station (WES) adaptation of the RMA-10 code developed by King (1993). This code computes time-varying open-channel flow and salinity/temperature transport in one-dimensional (1-D), 2-D, and/or 3-D, subject to the hydrostatic approximation. Vertical turbulence is supplied using a Mellor-Yamada Level 2 (Mellor and Yamada 1982) k-L approach modified for stratification by the method of Henderson-Sellers (1984).

The computational mesh (12,000 nodes) for this effort provided vertical resolution of 3 to 6 ft between nodes and horizontal spacing of 70 ft (in the channel) to 600 ft (in Trinity Bay). Figure 1 shows this mesh for existing conditions.

## Verification

The verification process of demonstrating the model's capability of producing the important features affecting the natural system is a requirement to show that the physics of the model is correct. The model layout and the manner in which the verification is undertaken are dictated by the type of testing that is to be conducted. In the case of the Galveston Bay 3-D study undertaken at the WES Hydraulics Laboratory, the prime interest was in the effects of channel deepening upon salinity intrusion and circulation of the bay. Ideally, this would be accomplished by the model demonstrating that it could reproduce salinity and circulation fields for previous channel dimensions. Unfortunately, this is usually impossible since sufficient data is rarely recorded at these earlier channel dimensions for a worthwhile comparison. However, the model can be shown to reliably reproduce present conditions over a range of hydrodynamic conditions. Therefore, the model must be able to not only show that it behaves like the natural system, but that it must do so as a result of

[1] U.S. Army Engineer Waterways Experiment Station; Vicksburg, MS.

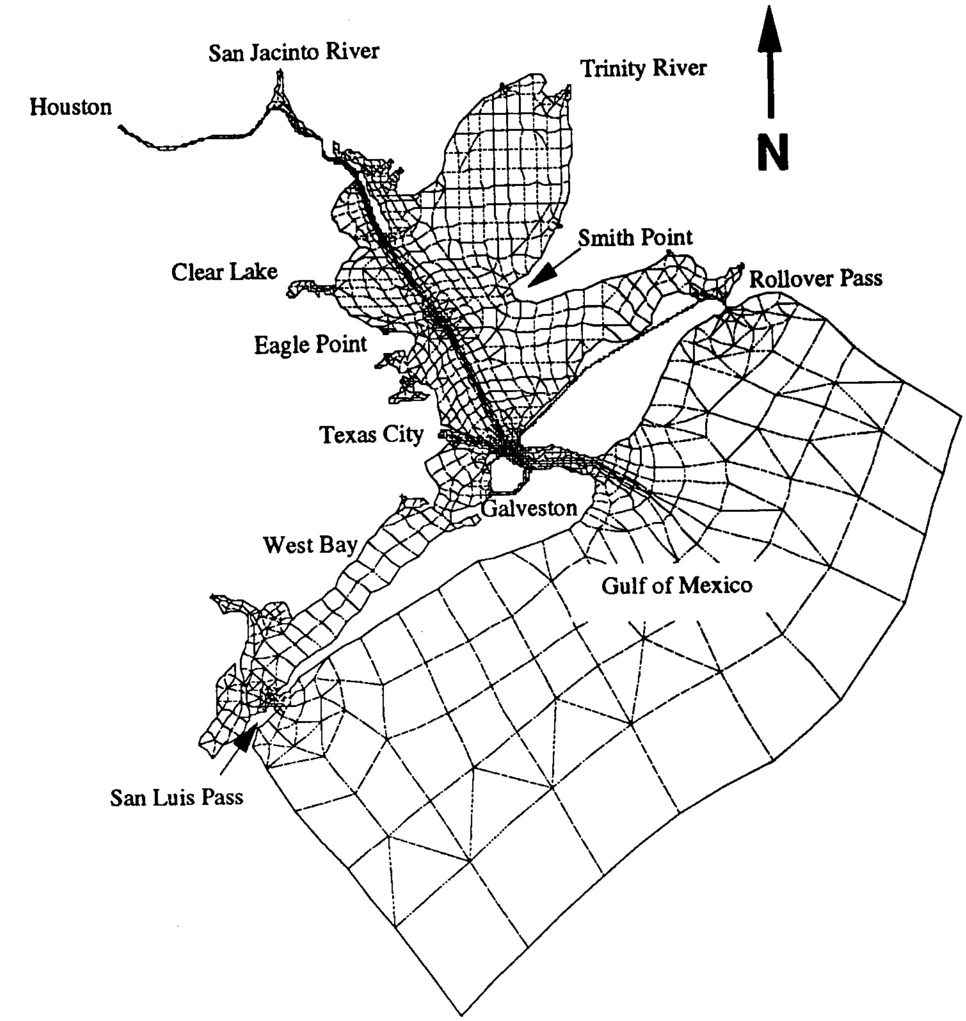


*Figure 1. Computational grid and location map for Galveston Bay*

the physics contained in the code and not as a result of the adjustment process alone.

In this study, the RMA10-WES finite element code was adjusted to a short set of data and then run with no further adjustment in comparison with some 6 months of tide, velocity, and salinity data collected throughout the bay. The degree of adequacy of the verification process, and thus the model reliability, was gauged against the uncertainty in the driving boundary conditions and the uncertainty in other salinity-based parameters used as input by the oyster model. The most limiting of these was sensitivity to driving boundary conditions. Model sensitivity to freshwater inflow and Gulf salinity provided a means to determine a minimum probable uncertainty of about 1.5 ppt salinity because of these boundaries. Additionally, the model residual circulation and flow and salinity patterns were compared with the characteristics of the natural bay described in the literature and through discussions with pilots and field personnel. The model demonstrates that it can produce the residual circulation, density currents, and flow patterns necessary to be a predictive tool.

While the verification process included tide and velocity as well as salinity comparisons, this article will concentrate on salinity because of limited space. Figure 2 shows the location of stations 7.0, 11.0, and 15.0, which are a small subset of the data collected over about 6 months. The salinity results for these stations are shown in Figure 3. The data record begins June 19, 1990, just after a major flood in the Trinity Basin. The model results are shown as the solid line and the moored field gauge results as dashed. The symbols represent hand-held field measurements made over several depths. The month or so of model results before approximately hour 4500 represents model spinup time and should not be under consideration. The figure shows that the model can follow a large salinity rebound quite accurately. Some statistics that quantify these results are shown in Table 1. The mean error and MAE are indicators of a shift in salinity from prototype to model. MAE is the mean of the absolute value of the error between model and field readings. These stations compare quite well with the probable uncertainty of the boundary conditions indicated by sensitivity analysis. The correlation coefficient is an indicator of how well the model follows trends. The statistic "d", proposed by Willmott (1982) and Willmott et al. (1985), is a fairly good indicator of any shifts as well as trends. Again the model compares well.

d is defined as follows:

$$d = 1 - \left[ \frac{\sum_i (M_i - P_i)^2}{\sum_j (|M_j^\nabla| - |P_j^\nabla|)^2} \right], \quad 0 \le d \le 1$$

where

$M_i$ = model reading i

$P_i$ = prototype reading i

$M_j^\nabla$ = model reading j minus average prototype value

$P_j^\nabla$ = prototype reading j minus average prototype value

**Table 1**
**Long-Term Salinity Verification Statistics**

| Station | Mean, ppt (Model-Prototype) | MAE ppt | Correlation | d |
|---|---|---|---|---|
| 7.0[a] | -0.3 | 0.8 | 0.97 | 0.98 |
| 11.0 | -0.3 | 1.3 | 0.85 | 0.91 |
| 15.0 | -0.8 | 1.8 | 0.89 | 0.94 |

[a] Based on hand-held meter readings taken during servicing.

In addition to these quantitative comparisons, we also investigated the characteristic behavior indicated by the model. These characteristic behaviors are important to feel confident that the model is a reliable reproduction of prototype. The model demonstrated important flow features such as a flood-dominant flow up the center of Trinity Bay with ebb channels along the outside edges of this bay. The ebb-dominate channel along the east side of Trinity Bay is responsible for the observed oyster kills near Smith Point during high-flow events. It also explains the low salinity observed in East Bay in spite of the very low direct freshwater inflow to this bay segment. The ebb-dominant current along the western shore of Trinity Bay appears to be responsible for observed lower salinity east of Atchinson Island in both the model and prototype. The model indicates a counterclockwise gyre in upper Trinity Bay in early spring that correlates with observed isohalines and pollutant concentrations. The model also shows the channel to be generally flood dominate over depth for the 25 miles of channel through the bay. This is in agreement with observations of Bobb et al. (1973) and Ward (1980).

## Conclusions

The 3-D numerical model RMA10-WES was successfully verified for use in the Galveston Bay, Texas, estuary. Salinity calculations were to an accuracy suitable for meeting the study needs, particularly as input to an oyster production model. The long-term behavior of the estuary was reproduced, as well as other characteristic behaviors of the system.

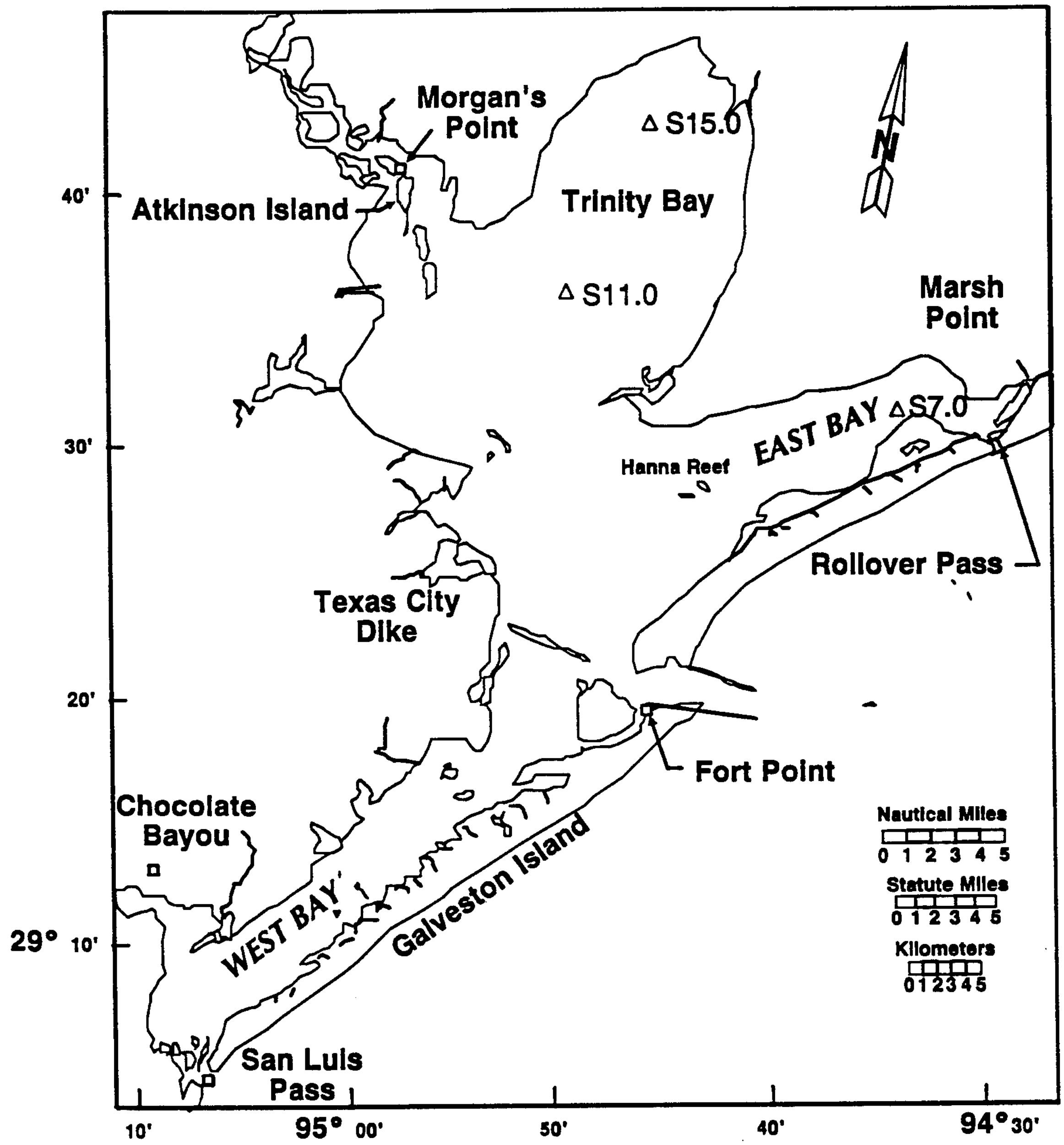


*Figure 2. Selected salinity station locations*

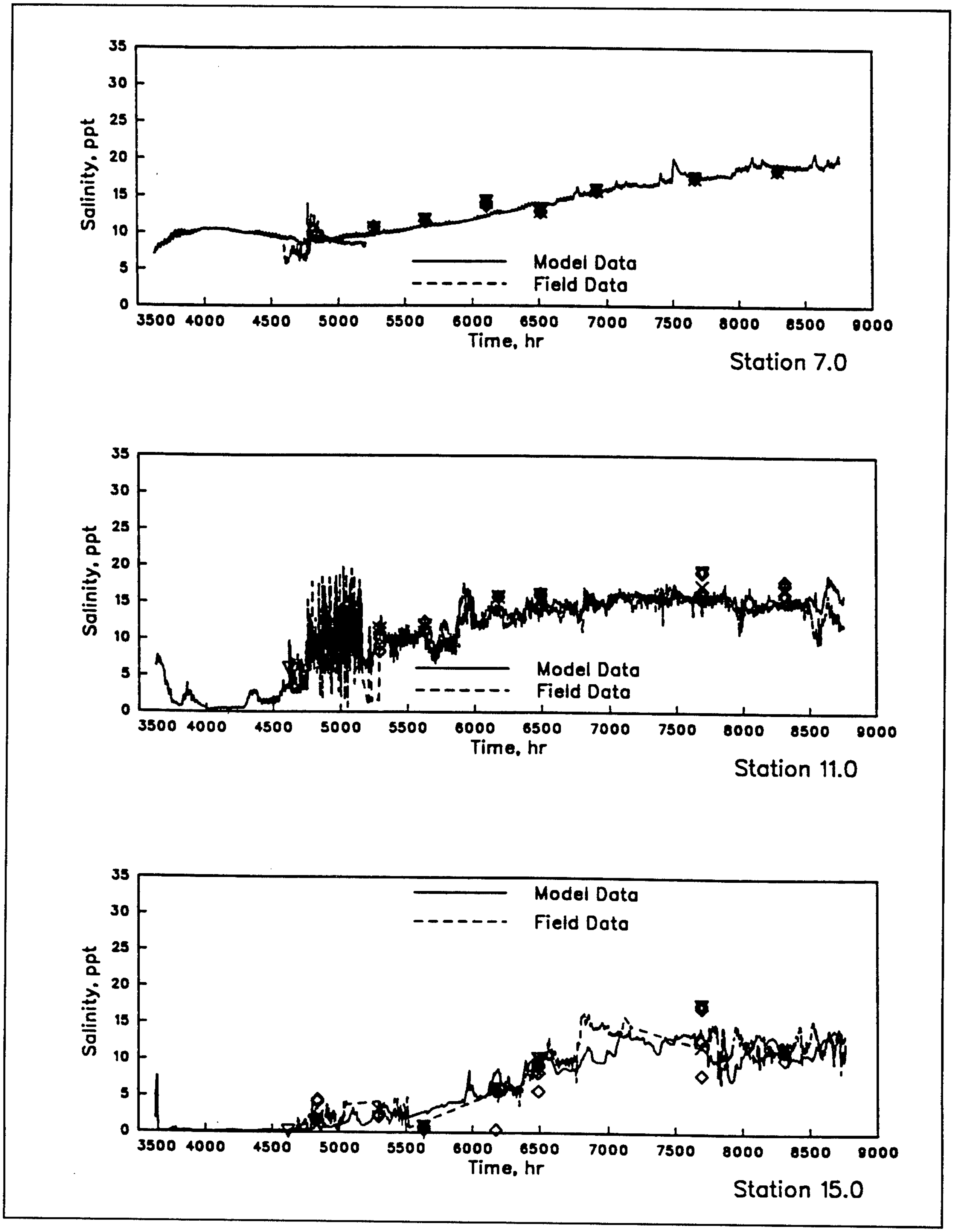


*Figure 3. Salinity comparison for model and prototype*

## Acknowledgments

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# Water Quality Problems Encountered on the Appomattox River During a Maintenance Dredging Operation

*by*
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## Background Data on the Project

The Appomattox River (Figure 1) has a history rich in the formation of our country. The first settlement of the area occurred in 1646 when Fort Henry was built on the site that is now the City of Petersburg. Near the fort, Major Peter Jones established an Indian trading station, which later grew into a village called Peter's Point. By the time of the Revolutionary War, this point was a thriving town known as Petersburg. The City of Petersburg was the site of the last major Civil War battle between Lee and Grant.

The Appomattox River, Virginia Federal Navigation Project (Figure 2) was authorized by the River and Harbor Act of 1871 and modified by the River and Harbor Acts of 1902, 1909, 1910, and 1927. The project consists of a channel 80 ft wide and 10 ft deep, from the mouth to the head of navigation at Petersburg, a distance of approximately 11 miles. It also includes a turning basin at downtown Petersburg. The project was constructed to presently authorized dimensions by 1931, with the last maintenance dredging of the full project performed in 1949.

## River Layout

A tributary to the James River, the Appomattox River drains 1,300 square miles. To reduce the sedimentation problem in the Navigation Channel, a second channel was constructed at the head of the tidal reach. Designated the "Diversion Channel," it was constructed in the late 1920s to divert the natural flow of the river, along with its heavy sediment load, downstream a distance of 5 miles where it rejoins the Navigation Channel in a naturally deep portion of the river. To maintain a freshwater flow and flushing action, a 3- by 3-ft box culvert was constructed at the head of navigation to connect the Diversion Channel with the Navigable Channel.

## Need for Project

Competitive rail cargo rates and a dwindling manufacturing economy forced all vessel traffic from the uppermost 3 miles of the Navigation Channel. However, commerce continued to be moved along the lower portion of the channel. Currently, over one million tons of cargo are shipped annually along the navigable portion of the river. Escalating railroad costs, increased demands for sand and gravel, and plans to revitalize the downtown waterfront for tourism have prompted the City of Petersburg to request that the badly shoaled portions of the river be restored to authorized dimensions.

## Design Problems

In October 1972, a storm passing over the Appomattox River watershed caused the worst flooding in the history of Petersburg. Reaching a flood stage in excess of 18 ft, the river overtopped the dike separating the diversion channel from the Navigation Channel, depositing tons of sediment into the upper reaches of the Navigation Channel and created a breach between the two channels at Station 150+00. The shoals left behind by the receding waters exceeded elevations of 5 ft mean low water at Station 20+00. As nothing

[1] U.S. Army Engineer District, Norfolk; Norfolk, VA.

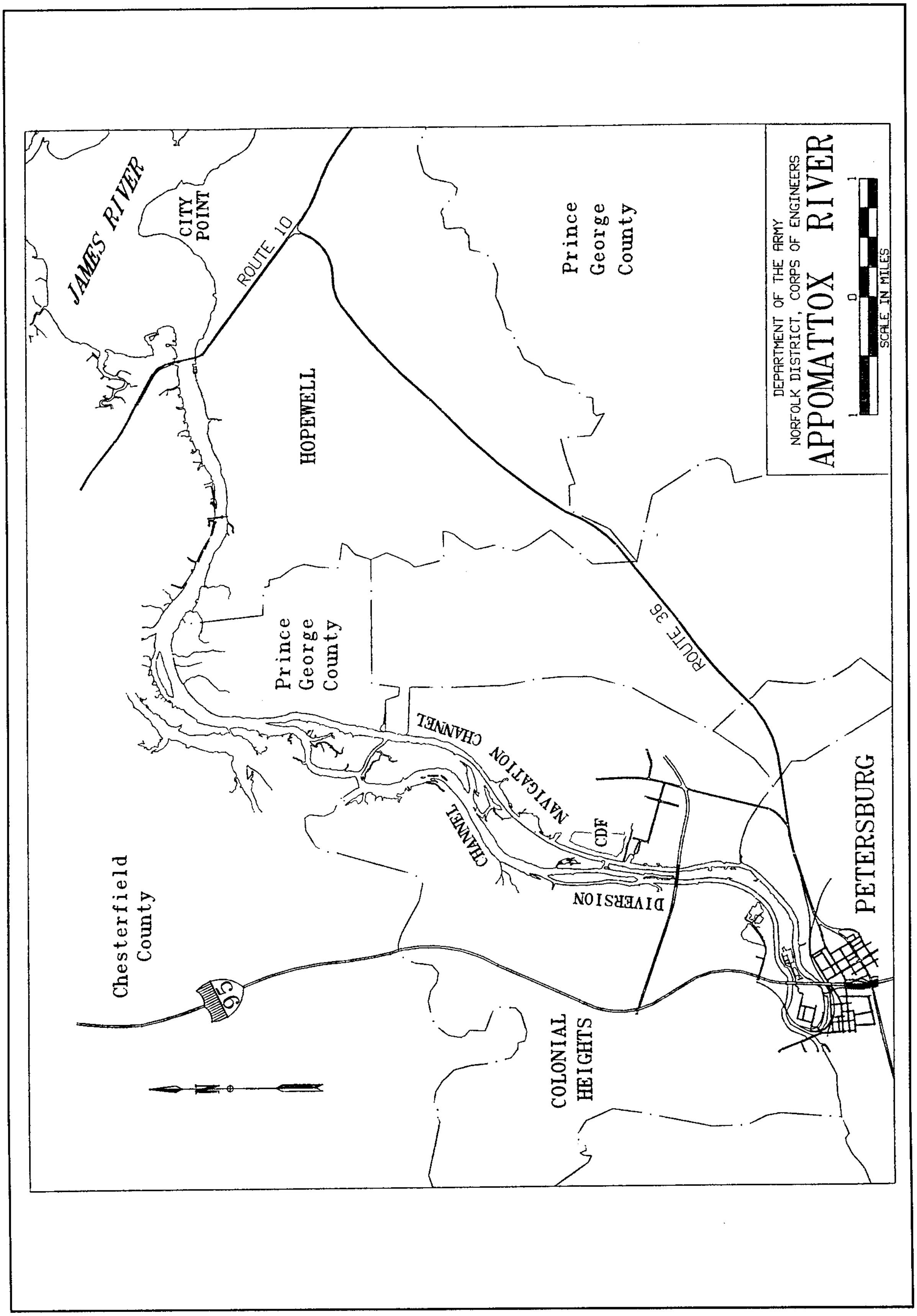


***Figure 1. Appomattox River***

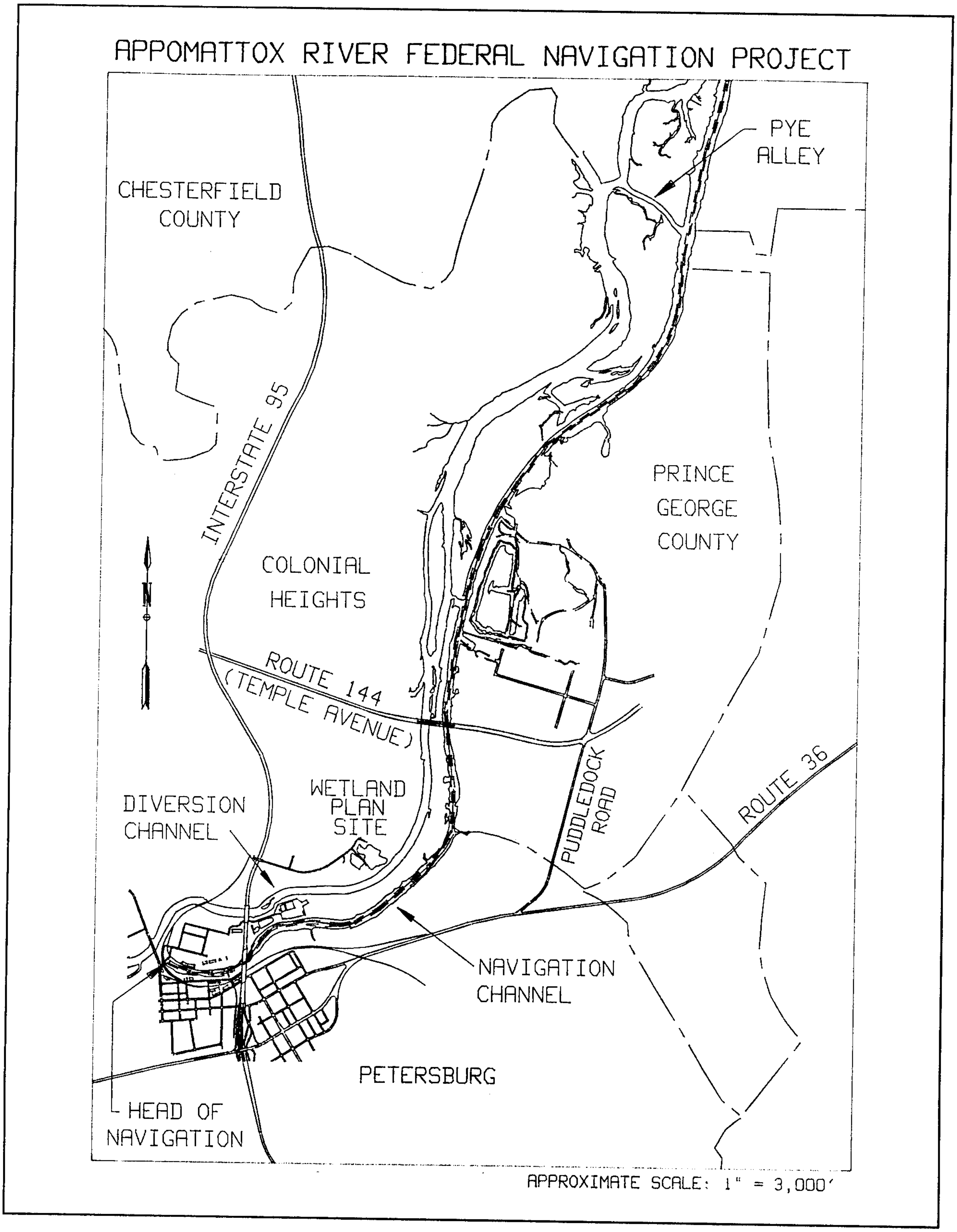


*Figure 2. Appomatox River Federal Navigation Project*

was done to restore the channel, nature began to take its course; by the late 1980s, 13 acres of intertidal and nontidal wetlands now occupied what was once the Federal Navigation Channel. Partial clogging of the culvert connecting the two channels left the channel almost stagnant, with only a small stream, Lieutenants Run, providing freshwater flow into the upper reaches. To restore the project, the channel needed to be dredged, the wetlands needed to be replaced, and the breach connecting the diversion channel to the Navigation Channel at Halls Island needed to be repaired.

## Project Start

Dredging was planned for a 5-mile reach of the project, with material placed in a confined disposal facility (CDF). During the initial phase of the project, the wetland area in the vicinity of Station 20+00 was cleared and grubbed. This construction activity unfortunately closed off the flushing action from the 3- by 3-ft box culvert and Lieutenants Run. The tributary flow was diverted west to the box culvert and on into the Diversion Channel. The discovery of petroleum hydrocarbon contamination in the sediments prevented any further activity that could restore freshwater flow to the Navigation Channel. In addition, the breach at Station 150+00 was closed off by Petersburg. These two activities would virtually shut off any fresh water from entering the Navigation Channel.

## Fish Kill

In mid-June 1992, a fish kill of approximately 5,000 to 10,000 gizzard shad was observed in the Navigation Channel. Virginia's State Water Control Board (i.e., the Board) made a site visit and concluded that high suspended solids and low dissolved oxygen (DO) levels were stressing the fish. On June 19, 1992, the Board requested that dredging cease because of DO readings as low as 0.2 mg/L, which is far below the minimum State standard of 4 mg/L.

One critical parameter that affected the DO concentration was the temperature of the water during the time of the dredging and subsequent fish kill. Temperatures averaged between 25 and 26 °C, which would indicate a DO saturation concentration between 8.4 and 8.2 mg/L. As the temperatures began rising into the summer months, it became more difficult for the Navigation Channel to return to an equilibrium DO condition.

Desiring to be fully cooperative with the State, Major Michael E. Lane, Contracting Officer for the Norfolk District, that same day ordered all dredging activities to cease while the fish kill problem was investigated. Dredging was stopped at Station 50+00.

## Analysis of the Problem

Using clearly defined landmarks, the Board established a sampling protocol for measuring temperature, pH, DO, turbidity (using a Secchi dish) and Redox potential. After 2 weeks of sampling, it seemed that the river had stabilized to a DO level of around 3.0 mg/L in the vicinity of the CDF outfall, which was still below the State standard. However, the Redox potential had stabilized enough for the fish to be considered out of danger.

Because the Board felt that the fish kill was caused by the low concentration of dissolved oxygen in the water because of the silt buildup, a reaeration solution was suggested for replenishing the DO. They recommended that the dredging equipment be used to pump the fresh water from the Diversion Channel at Station 150+00 into the Navigation Channel at Station 50+00. Although the Norfolk District agreed to this action, they felt that, considering the volume of the Navigation Channel compared with that of the pumping activity, little if any replenishment would occur. This appeared to be the case, since after 24-hr of pumping, there was no discernible increase in DO. The State also requested that sampling

be performed on the CDF for biological oxygen demand (BOD), pH, TS, TSS, and TVS. They were concerned that the DO depletion was being caused by a BOD.

## Initial Suggestions for Resolution

The first thoughts for reaeration centered on the CDF since it was considered to be the source of BOD contamination. DO readings were below 2.0 mg/L in the containment pond. Therefore, it was initially decided to look at ways of getting oxygen back into the CDF. The question was whether to look at the CDF as a gigantic lagoon and use surface aerators to increase the oxygen, or simply aerate the discharge back into the river. Since the water in the CDF had to be removed in order to start up dredging again, the latter was chosen as a temporary solution by simply utilizing a fan-tip nozzle to spray the discharge over the river.

The official protocol established by the Board was to wait until the river DO reached 4 mg/L before resuming dredging and then observe the DO in the area of the dredge and at the outfall of the CDF. If the DO dropped below 3.0 mg/L, the operation was to cease again.

It was also decided to evaluate the sediment in the part of the channel that remained to be dredged. The theory was that if there was an understanding of the amount of BOD in the sediment, the oxygen demand could be determined and the CDF reaeration process could be engineered to handle the load. Prior to developing a full analysis on the remaining material to be dredged, a trial testing procedure was developed to best determine how to approach testing for the various parameters needed in resolving the DO problem. The U.S. Army Engineer Waterways Experiment Station (WES) was consulted in setting up the sampling procedures, and a trial run was performed by the Norfolk District on August 10, 1992. WES recommended that since the CDF effluent was the probable cause of the DO depression and not the dredging resuspension, a modified elutriate test should be performed that would better duplicate the expected conditions in the CDF.

It was decided that, in addition to the chemical oxygen demand (COD) and BOD tests requested by the Board, testing for the immediate oxygen demand (IOD) should also be performed. Thus, ammonia, sulfides, and reduced iron were included. Once these compounds were released into the water column, they would oxidize and uptake the available DO in the water.

The trial samples were obtained using a hand auger. Three centerline stations were analyzed, retrieving samples at depths of 4 and 8 ft. Samples were placed in airtight bottles, put on ice, and delivered to the laboratory on the same day. The results are given in Table 1.

**Table 1**

| Station Depth, ft | COD | BOD | TKN | $NH_3$ | Sulfides | Red Iron | TS | TSS | TVS | Coli-Bacti |
|---|---|---|---|---|---|---|---|---|---|---|
| 29+26 4 | 19 | 5 | 4.53 | 0.84 | 6 | 0.05 | 2480 | 2310 | 326 | 1400 |
| 29+26 8 | 20 | 4 | 4.64 | 11.45 | 6 | 0.16 | 1390 | 1340 | 202 | 6 |
| 33+29 4 | 36 | 7 | 14.30 | 29.93 | 10 | 0.32 | 6160 | 5700 | 774 | 300 |
| 33+29 8 | 49 | 20 | 29.40 | 90.98 | 21 | 0.49 | 10400 | 10600 | 1340 | 100 |
| 36+00 4 | 20 | 10 | 12.70 | 55.67 | 10 | 0.11 | 2500 | 2090 | 356 | 100 |
| 36+00 8 | 36 | 17 | 15.45 | 79.08 | 11 | 0.46 | 3020 | 2940 | 438 | 200 |
| River water | 29 | 3 | 1.8 | 0.19 | <1 | 1.95 | 156 | 48 | 32 | 700 |

It is noted that the BOD and COD values were not as significant as the State originally felt as being the cause of the DO depletion. BODs from the CDF and its outfall seemed to be within typical ranges for dredging projects. In the evaluation of the IOD, the sulfides may have played a significant role, since for every sulfide molecule available, an oxygen molecule is depleted. This would have to be studied further in a controlled experiment. The high $NH_3$ values may also be of concern because theoretically for every molecule of ammonia nitrified, 4.6 molecules of oxygen are required.

The conclusion reached from this trial run was that too much variability existed within the different sediment samples to continue an in-depth analysis of the dredged material for the purpose of determining an oxygen demand for reaerating the CDF. Instead, it seemed more practical to determine a way to flush the Navigation Channel with fresh water from the Diversion Channel.

## Research on River Dynamics

Based on a 1985 Data Report on the Appomattox River,[1] when both Stations 20+00 and 150+00 were not closed off, the tidal cycles were plotted out, showing that the breach was affecting the current flow in and out of the Navigation Channel. By filling in the breach, the river dynamics were changed, wherein the Navigation Channel was no longer providing a flushing action by the main river flow. In addition, the shoaling at Station 20+00 caused a further elimination of any additional flushing and the Navigation Channel between the CDF outfall and Station 20+00 virtually became a filled bathtub (overhead). The tide would rise and fall, but little flushing was occurring to assist in replenishing the DO concentration.

Once the dredging began and the CDF was discharging back into the bathtub, it would be a matter of a few days before the area around the CDF discharge became saturated with suspended solids to the point where DO concentrations were lowered to critical levels. In addition, it was estimated that between 6 and 11 days would pass before the dredging operation began recycling the water from the CDF effluent. This would result in additional suspended solids being added to the already concentrated discharge from the CDF. This scenario seemed to correlate well with the dredging operation (Figure 3). Thus, if the dredging were to be resumed under the existing conditions, then it was estimated that the contractor would have about 6 days to complete the dredging. These estimations were based on the Streeter-Phelps Equation:

$$D = \frac{k_1 L_o}{k_2 - k_1}(10^{-k_1 t} - 10^{k_2 t}) + D_o(10^{-k_2 t})$$

where

$D$ = dissolved oxygen deficit in time t, mg/L

$k_1$ = deoxygenation rate, per day

$L_o$ = initial ultimate carbonaceous BOD, mg/L

$k_2$ = reaeration rate, per day

$t$ = time of travel, days

$D_o$ = initial DO deficit at t = 0, mg/L

An alternate discharge of the CDF effluent was into the Diversion Channel (i.e., the main river). This analysis was coordinated with the Board, and the Streeter-Phelps Analysis indicated that the main river could easily absorb the additional BOD load from the CDF outfall. The analysis included using a record low-flow condition during the winter months.

1 Data Report, 1985, "Hydrodynamic and water quality measurements in the Appomattox River - A report to the City of Petersburg," VIMS Data Report No. 25, Department of Physical Oceanography and Environmental Engineering, Virginia Institute of Marine Science and School of Marine Science of The College of William & Mary in Virginia, Glouester Point, VA.

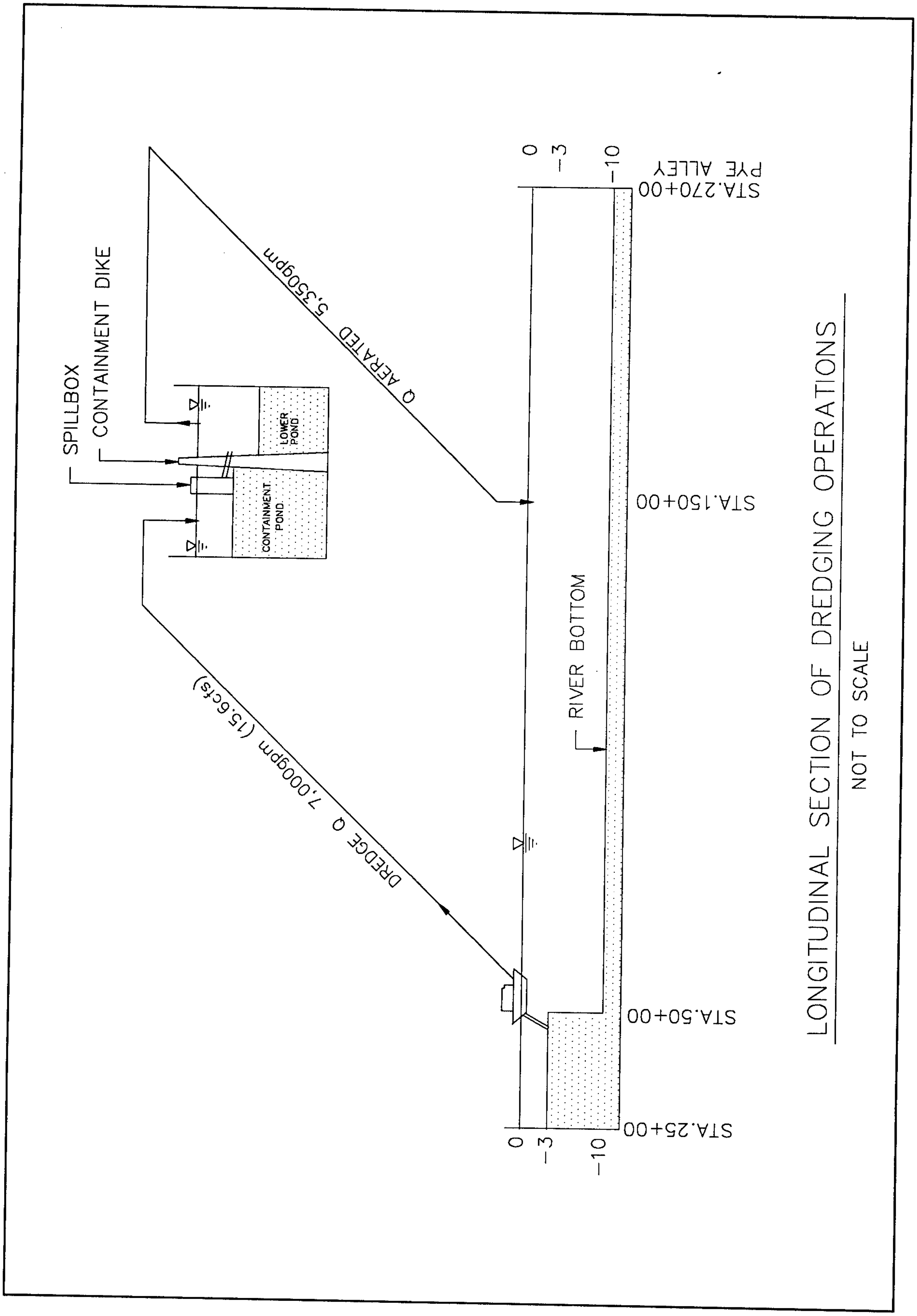


*Figure 3. Longitudinal section of dredging operations*

Suspended solids impact on the mixing zone of the Diversion Channel was analyzed using a simplistic two-dimensional calculation based on dispersion principles. WES Technical Note EEDP-04-5 (Interim Procedures for Estimating Mixing Zones for Effluent from Dredged Material Disposal Sites - Single-Point Discharge) provides general guidelines for estimating the length and width of mixing zones created by a single point-source CDF effluent.[1] The use of this analysis resulted in the mixing zone for the suspended solids occurring far past the mouth of the Appomattox and into the James River.

A meeting was held with the State Water Control Board to resolve the problems caused by the fish kill and to present the preferred method of discharging the CDF effluent into the main river to avoid another detrimental DO deficit in the Navigation Channel. The State, however, preferred to continue the discharge into the Navigation Channel because of the public concern from seeing higher turbidity levels in the main river. Their analysis showed that under winter conditions, the Navigation Channel would be able to sustain a suspended solids increase from the remaining dredging operation. However, when their analysis was critiqued, it was found that it assumed that the Navigation Channel would be flushed by the Diversion Channel all the way up to Station 0+00, an impossible situation considering the existing blockages.

The issue has yet to be resolved because of the fact that petroleum hydrocarbon contamination in the area of the wetlands was found to be in the portion of the channel remaining to be dredged. The status of the project is presently on hold, and every effort will be made to convince the Board that the CDF discharge point should be re-established into the main Diversion Channel instead of the Navigation Channel in order to avoid another fish kill.

1 Memorandum, 1992, Paul A. Zappi and Joseph V. Letter, Jr., "Upland dredged material placement site effluent monitoring strategy, maintenance dredging, Hudson River, NY," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

# San Francisco Bay Dredged Material Disposal Management—The Saga Continues

*by*

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## Introduction

At the U.S. Army Corps of Engineers' eighth and ninth seminars on Water Quality, members of the U.S. Army Engineer District, San Francisco, described their planning and management activities for dredged material disposal in the San Francisco Bay region. Over the years since those seminars, the District's involvement in these activities has evolved from a single agency initiative to a $16 million, multiparticipant project. The framework for the project was developed into the Corps' five-phase Long-Term Management Strategy (LTMS) format. The time frame for the San Francisco LTMS is 50 years. The scope of the project encompasses all present and future activities related to the relocation of dredged material from ports and navigation channels in the region. This includes efforts to use this material as a resource.

The San Francisco District is presently proceeding with this work in coordination and cooperation with the U.S. Army Engineer Division, South Pacific, the U.S. Environmental Protection Agency, other Federal and State agencies, ports, and development interests, as well as environmental and fishing groups. However, unlike the earlier reported activities where the Corps had solely supported the Disposal Management Program (DMP) and managed its implementation, the current program is a partnership. The partnership was formed after Headquarters guidance to the South Pacific Division in Fiscal Year (FY) 1990 stated that the Corps should not be required to carry the full financial burden of the proposed DMP studies. As State and other local navigation interests were solicited to contribute funds, they expressed their desire to have control over the expenditure of those funds as well as management of the program. Hence, because of local pressure from these potential cost-sharing partners, the DMP was reorganized into the multiparticipant LTMS. The Corps decided to share its planning and management responsibilities for the work as well as funding requirements. A consensus building process was initiated that included opportunities for enhanced cooperation.

This consensus approach has required that the participants strive for a partnership between the involved parties at the executive, management, and working levels to define the study program, oversee results, and manage its financing. At the LTMS Phase III completion in August 1994, there will be a draft Management Plan that will define the locally developed strategies and policies to sustain viable disposal options for the ports and channels in the San Francisco region. The subsequent adoption of this strategy by Federal and State agencies will improve project sponsor's certainty regarding timing and regulatory requirements for future dredging projects. This paper is a continuation of the papers presented at the eighth and ninth seminars and describes the subsequent evolution of management for the LTMS program, the technical work being completed, and the consensus building process utilized for the successful implementation of the program.

[1] U.S. Army Engineer District, San Francisco; San Francisco, CA.

## Background

Nationwide, dredged material disposal sites have become an increasingly limited resource because of either limited existing capacity, lack of new locations, or environmental concerns. Over the last several years, the San Francisco Bay region has been faced with disposal site uncertainty because of all of these conditions. Annually, more than $5.4 billion of economic activity is directly dependent on the deep and shallow draft navigation channels in the Bay region (Beeman & Associates, Inc. 1990). These channels have an annual disposal requirement of approximately 5 million cubic meters (Mcm) for their continued maintenance. The region also has a one-time new work requirement of approximately 13 Mcm for the Oakland Harbor (4 Mcm), Richmond Harbor (1.5 Mcm), and the John F. Baldwin Phase III Navigation Channel (7.5 Mcm). Insufficient capacity exists with present regional disposal options to accommodate these maintenance and new work projects. There are no presently authorized ocean or upland alternatives for this material. Further, both Federal and State resource agencies are calling for closure of the most used disposal option—in-Bay, open water—because of environmental concerns.

Wakeman, Chase, and Roberts (1990) and Wakeman and Stradford (1992) previously described the activities of the San Francisco District and the South Pacific Division to manage regional dredged material disposal. In summary, the Corps and approximately 40 other Federal, State, and local navigation interests organized to meet this challenge. In January 1990, they formed a new entity and initiated a regional planning process framed by the Corps' LTMS approach (33 CFR Part 337.9; Francingues and Mathis 1989). The LTMS consists of five phases: Phase I, Evaluate Existing Management Options; Phase II, Formulate Alternatives; Phase III, Analysis of Alternatives; Phase IV, Implementation; and Phase V, Review and Update. The group established a hierarchical management structure led by an Executive Committee. The Executive Committee is composed of the Corps of Engineers (COE) South Pacific Division Commander, the U.S. Environmental Protection Agency (EPA) Regional Administrator, the San Francisco Regional Water Quality Control Board (RWQCB) Chairperson, the San Francisco Bay Conservation and Development Commission (BCDC) Chairperson, and the State Dredging Coordinator. This committee is advised quarterly by the interested and affected parties (collectively called the Policy Review Committee) to foster consensus building on pertinent issues. At the next tier is the Management Committee. It is drawn from each agency's District Engineer level and oversees the LTMS planning, budget, and schedule. Technical work is performed by four teams (or Work Groups) under the direction of the Management Committee.

The San Francisco LTMS process was initiated by an up-front allocation of $2.5 million by Corps Headquarters for FY90. As called for under the adopted five-phase process, a Phase I document was prepared, reviewed, and adopted by the Executive Committee (U.S. Army Corps of Engineers 1990). Its results indicated that a broader disposal array was necessary to meet the region's future dredging requirements. Before commencing Phase II, the Executive Committee adopted four goals to guide future activities. These include the following: (a) to maintain in an economically and environmentally sound manner those channels necessary for navigation in the San Francisco Bay and estuary and eliminate unnecessary dredging activities in the Bay and estuary; (b) to conduct dredged material disposal in the most environmentally sound manner; (c) to maximize the use of dredged materials as a resource; and (d) to establish a cooperative permitting framework for dredging activities. These goals will guide Phase III analyses and Phase IV actions. Thereafter, the participants spent more than a year detailing the nature and extent of technical studies necessary to assess the acceptability of present disposal practices and to identify new disposal alternatives. They crafted a study plan (U.S. Army Corps of Engineers 1991) to guide the conduct of $10.8 million in technical studies

over four and one-half years. These studies were designed to seek disposal options in the ocean, in-Bay, and upland. Four agencies (COE, EPA, RWQCB and BCDC) were charged with providing the bulk of the staff support for the project's overall administration and study management at a cost of $5.3 million.

In September 1989 with receipt of the initial $2.5 million, the South Pacific Division and San Francisco District had been directed to solicit the remaining LTMS funds from the State or regional interests. Although the District was actively pursuing local cost participation for the LTMS in FY91, the Conference Report of the Energy and Water Development Committee, House of Representatives, September 7, 1990, stated: "In order to provide for economically viable and environmentally sound regional solutions to the dredging problems, the conferees direct the Corps of Engineers to fully fund the necessary studies from its Operations and Maintenance account for the development of a long-term dredge material disposal plan for the San Francisco Bay region." Activities to obtain voluntary cost participation from local ports continued into FY92 when a letter from Mr. Alexander Krygsman, President, Golden Gate Port Association (GGPA), dated January 6, 1992, was sent to Ms. Nancy Dorn, Assistant Secretary of the Army, and asked for the Corps' reconsideration of the issue of LTMS cost sharing. Mr. Krygsman, in a letter sent the same day to the San Francisco District Commander, stated: "The members of GGPA, at this time, cannot agree to even more cost-sharing of the LTMS..." (that is, beyond fees already levied by State agencies and collected under the Harbor Maintenance Trust Fund). A return letter from Ms. Dorn, dated 7 April 1992, replied that "...we have sought and will continue to seek voluntary non-Federal participation in the San Francisco LTMS study." However, she went on to say that these issues "...have highlighted the need to develop uniform and effective national policies to deal the funding and management of LTMS studies." Since this exchange of letters, a new national policy (PGL No. 40) was issued; however, it did not elicit a port voluntary cost share for the San Francisco LTMS.

## Technical Studies

The initial thrust of the LTMS process was to develop an array of acceptable disposal options for the region. The study plan, technical activities, and staffing responsibilities were divided between the three potential disposal locations: ocean, in-bay, and upland. The EPA, Region IX, was tasked with the lead for "Ocean Studies" for ocean disposal site designation under section 102 of the Marine Protection, Research and Sanctuaries Act. The RWQCB took the lead on "In-Bay Studies" to determine the environmental acceptability of current practices and to locate new sites, if appropriate. The BCDC accepted the responsibility to lead the "Upland Studies" that also encompassed the studies to identify and explore opportunities for beneficial uses, locally called "reuses," of dredged material. (Because of existing terminology under the California Water Code, the term "beneficial reuse" was coined to differentiate from other State defined beneficial uses.) The COE, both San Francisco District and South Pacific Division, was tasked with overall coordination and management of the LTMS program. In addition, it was anticipated that the Corps would provide the necessary integration of LTMS outputs to ensure implementation of the selected strategy.

The majority of the project's technical costs were associated with ocean site characterization studies (52 percent). In-Bay studies accounted for about a quarter (27 percent), and upland studies were about an eighth (14 percent) of the technical costs. Remaining costs were related to planning and documentation. The annual costs of the studies and agency staffs are displayed in Table 1.

## Ocean Studies

A critical element in the ocean studies process is the adequate description of changes in

**Table 1**
**Study and Staff Costs ($000)**

| Year | FY90 | FY91 | FY92 | FY93 | FY94 | Total |
|---|---|---|---|---|---|---|
| **Study Requirements** | | | | | | |
| Planning | 196 | 83 | 96 | 0 | 0 | 375 |
| Ocean | 1,217 | 3,608 | 785 | 0 | 0 | 5,610 |
| In-Bay | 919 | 1,093 | 447 | 437 | 96 | 2,992 |
| Upland | 159 | 194 | 540 | 553 | 59 | 1,505 |
| EIS/EIR | 0 | 0 | 0 | 93 | 300 | 393 |
| Subtotal | 2,491 | 4,978 | 1,868 | 1,083 | 455 | 10,875 |
| **Staff Requirements** | | | | | | |
| COE | 457 | 710 | 662 | 595 | 500 | 2,924 |
| EPA | 200 | 200 | 200 | 200 | 200 | 1,000 |
| RWQCB | 150 | 150 | 150 | 150 | 150 | 750 |
| BCDC | 65 | 109 | 154 | 154 | 154 | 636 |
| Subtotal | 872 | 1,169 | 1,166 | 1,099 | 1,004 | 5,310 |
| Total | 3,363 | 6,147 | 3,034 | 2,182 | 1,459 | 16,185 |

oceanographic seasons offshore of San Francisco. This requirement for a complete record of seasonal changes necessitated more than a year of field investigations. The local upwelling period begins in the April-May time frame and is key to the movement of nutrients and fish off the coast. In order to incorporate this event, EPA's field work was initiated prior to adoption of the final study plan in June 1991. An oceanographic survey of bathymetry in the Gulf of Farallones was completed in August 1990. From the preliminary survey, a detailed mosaic of the ocean floor was constructed in water depths from 30 to 3,000 m. This work provided details on the areas bathymetry, material composition, and stability. The results of the survey allowed preparation of a detailed ocean site study plan including current measurements, numerical modeling, and benthos assessment.

The Ocean Studies Work Group completed its ocean site characterization studies, which included gathering data on sediments, currents, benthic organisms, fish, birds, mammals, and other significant study parameters at five areas off San Francisco in March 1992. Analysis of the collected sediment, organism, and current data were completed and presented in the draft site designation Environmental Impact Statement (EIS) issued December 1992. Thirty-five comment letters were received addressing concerns primarily related to site-monitoring requirements. The final EIS was released in August 1993. It identifies EPA's preferred alternative site located 93 km (50 n.m.) in 2,500 to 3,000 m of water. The preferred site corresponds to the site approved by the Corps and EPA to receive dredged material (approximately 1 Mcm) from a Navy project under a section 103 permit. The final rule was published in the Federal Register in January 1994, and the site's final designation was completed in February.

## In-Bay Studies

In early 1990, the San Francisco Estuary Project (SFEP) published a status report that listed several environmental concerns with regional dredging activities (SFEP 1990). Their report identified data gaps that guided the In-Bay Studies portion of the LTMS Study Plan. A key concern was the effectiveness of the regulatory methods for determining the quality of sediments approved for in-Bay disposal. It called for the determination of the fate and transport of in-Bay disposed sediments. It recommended an assessment of the biological effects of these discharged sediments, including bioaccumulation and physical impacts of suspended solids on sensitive life stages. The objectives of the in-Bay studies were to close these gaps and to identify new in-Bay disposal sites that were environmentally acceptable.

The In-Bay Studies Work Group worked to fill these data gaps by a combination of approaches that utilized analyses of existing data, numerical modeling, field work, and laboratory studies. The analysis of project and reference data for sediment quality led to promulgation of new regional testing protocols (Public Notice 93-2). Field work was commissioned in March 1992 to develop a broader understanding of the physical system and natural suspended solids loading. The results were incorporated into two separate modeling efforts to predict sediment movement and concentrations. Studies of sublethal biological effects and bioaccumulation were conducted in the laboratory and in the field. Findings are being employed to evaluate the long-term acceptability of in-Bay disposal on biological resources. Other than toxicity, biological effects stem principally from burial and habitat alteration from solids. Field work to determine areal extent of these short-term impacts was initiated in August 1993. In addition, the work group addressed administrative concerns, including development of a data management system and a standard methods manual for chemical and biological analyses of San Francisco Bay sediments. To date, direct evidence of harmful biological impacts to fisheries resources because of in-Bay disposal have not been demonstrated; nevertheless, environmental groups, fishermen, and resource agencies oppose any new open-water, in-Bay sites. Capping is a new technique that may be determined to be regionally, environmentally acceptable. Studies at a proposed nondispersive site (Bay Farm Borrow Pit) may lead to one additional in-Bay disposal site being designated.

## Upland/Reuse Studies

The objectives of the Upland/Reuse Work Groups' studies are as follows: (a) to identify, develop, and analyze opportunities and constraints for the use of dredged material as a resource in the San Francisco Bay and Sacramento/San Joaquin Delta areas and for the disposal of contaminated sediments; (b) to analyze and resolve reuse and upland disposal constraints through working with interested parties, filling information gaps, performing demonstration projects, and recommending site-specific plans for reuse and disposal opportunities; and (c) to develop and evaluate implementation strategies for upland disposal plans. A study of potential sites was initiated in January 1992. The overall intent of this first level feasibility analysis was to focus the efforts of the succeeding work on the most promising reuse opportunities and feasible contaminated sediment disposal methodologies paired with specific local upland sites. Eighty sites were arrayed and ranked according to engineering, environmental, and land-use factors. Three sites were selected for development to a conceptual design level—two wetland restoration sites and a containment site. Another study analyzed the advantages and disadvantages of two potential rehandling facilities. In FY94, the U.S. House of Representative's Appropriations Committee provided $300,000 for reconnaissance studies at one of these sites, Leonard Ranch.

Currently, the Upland/Reuse Studies Work Group is preparing generalized plans for various categories of reuse projects or confined disposal facilities considered feasible during the earlier studies. Further, work is underway

to develop a regional plan for reuse (whether in landfills, wetland restoration, or levee stabilization) and upland sites that refines the siting feasibility analysis previously completed. This combination of activities is facilitating regional upland siting interest and considerations by local landowners and project sponsors. At a minimum, it seems likely that the region will have two new reuse sites available to receive dredged material in mid to late 1994: Sonoma Baylands and Montezuma Wetlands Restoration projects. These two sites, one on the margin of San Pablo Bay and the other on Suisun Bay, have a combined disposal capacity of approximately 20 Mcm.

## Implementation Activities

Over the first few years of the LTMS, attention was focused on asking the right technical questions and obtaining their answers. As these questions became resolved and technical findings were being developed, new questions of a nontechnical nature began to emerge. It became increasingly clear that having the facts, although necessary, was not going to be sufficient to guarantee that the LTMS would be implementable. There were legal, institutional, financial, and policy constraints that could derail the best plan. These issues needed specific attention for the LTMS to succeed.

At their May 1992 meeting, the Executive Committee established a fourth work group to tackle this array of legal, procedural, and policy issues that could adversely impact LTMS implementation. The objectives of the Implementation Work Group are as follows: (a) to coordinate, integrate, and institutionalize the disposal site recommendations and products of the Ocean, In-Bay, and Upland/Reuse Work Groups into implementable strategies and procedures; (b) to develop strategies and procedures that provide balance between environmental and economic factors during LTMS implementation, emphasizing sustainability of each over the 50-year planning horizon; and (c) to provide guidance for the preparation of LTMS management plan and environmental documents to include early consideration of the completeness and integrity of the work to support these final documents. Over the next 6 months, five task committees were established to handle specific issues, including upland site financing, confined disposal options, permit coordination, and environmental review. By December 1992, the Environmental Review Task Committee had finalized their recommendation. They advised that a programmatic EIS was needed to obtain public comment on potential changes in regulatory decision making under the LTMS Management Plan. The Management Committee concurred at its January 1993 meeting that a policy EIS and Environmental Impact Report (EIR) should be prepared for the LTMS. In March and April, the Management Committee participated in a policy Delphi process to develop an array of alternative policies for consideration and examination during the public review process. At their April meeting, the Executive Committee and Policy Review Committee were advised of the Management Committee's decision and were presented with the results of the Delphi process and a draft Notice of Intent. The draft Notice of Intent identified the Corps of Engineers as the lead Federal agency; it did not identify a State lead agency. Comments received on the draft notice from the Policy Review Committee stated that the EPA was the preferred Federal lead agency and that the California State Water Resources Board was the preferred State lead. Thereafter, the Management Committee decided that these agencies would be identified as the leads in the Federal Notice of Intent and State Notice of Preparation. Scoping meetings for the EIS/EIR were held in July. The process is underway and is scheduled to deliver a draft in August 1994 with the Management Plan.

## Management Plan

The LTMS Management Plan envisioned in 1990 was merely a mechanism to restate the currently utilized policies while providing a broader array of disposal options for regional use. The approach assumed continued singular Federal and State agency unilateral

decision making—each agency pushing its own mandate and policies. This approach has caused pathetic regional management of dredging and disposal at its best and economically and environmentally damaging mismanagement at its worst (General Accounting Office 1989).

As the members of the LTMS agencies (executives and staffs) interacted and strove for consensus with the involved parties, a working partnership emerged. By 1993, the five agencies pictured themselves in a collaborative effort with a higher purpose than just identifying new sites. The project purpose, as stated in the first LTMS goal, evolved into developing a coordinated, Federal-State strategy for cost-effective and environmentally sound management for dredging and disposal while maximizing beneficial reuse. To reach this purpose, each agency had to consider the policy position they take when evaluating dredging projects. For example, the Corps uses the Federal Standard to select a suitable disposal option. The Federal Standard (33 CFR 335.7) is based on the Corps identifying the least cost alternative that meets Federal environmental statutes. This policy is not consistent with EPA's policy of favoring the environmentally preferred, practicable alternative. The quagmire grows when State policies with their perspectives are added, sometimes in direct conflict with Federal policies. Resolution of these policies' conflicts can be contentious, time-consuming, and expensive—frustrating project sponsors with "mudlock."

The EIS/EIR was initiated to aid the LTMS agencies in exploring dredging policies that comply with Federal and State statutes and meet the LTMS goals. It has been formulated to identify and evaluate an array of dredged material management options and to help frame the policy choices for the LTMS. Through this process, the Executive and Management Committees propose to gather additional public input enabling their selection of a preferred dredged material management policy or policies under Phase III. The Management Committee participation in the policy Delphi process is indicative of their desire to develop a cooperative Federal-State policy and to harmonize their regulatory approach. The process will continue with the development and, ultimately, adoption of the LTMS Management Plan by the Executive Committee. This plan will reflect the preferred management policy identified under the EIS/EIR and will be used by all regulatory agencies to foster efficiency and effectiveness in dredging project decision making.

## Unanticipated Products

The LTMS project has provided the substrate for the germination and growth of a new governmental approach to dredging and disposal activities in the San Francisco Bay region. A Federal-State partnership has emerged that overshadows past wasteful and narrowly focused practices that were harmful to both the economy and the environment. Although the LTMS was established as a joint undertaking for the outset, the depth and vitality of this interagency partnership are unanticipated products of the consensus process.

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# Long-Term Management Strategy for Maintaining Savannah Harbor

*by*
*Susan E. Durden*[1]

## Introduction

Operation and maintenance (O&M) of the Nation's navigable waterways is the responsibility of the U.S. Army Corps of Engineers (COE). The Corps' performance of O&M activities is of interest to many groups from fisheries biologists to international shipping companies to industries (Barr 1987). Local government plays a special role. As the "local assurer," it is their responsibility to provide disposal areas for dredged material. This is a unique partnership with each party dependent on the other's timely performance of his duties.

To coordinate these many interests and to ensure the most efficient operation of the harbor for the long term, including the availability of disposal sites, the U.S. Army Engineer District, Savannah, has undertaken the development of a Long-Term Management Strategy (LTMS) for Savannah Harbor (Figure 1). The harbor is a benefit to Georgia in many ways—as a unique habitat, an avenue for international commerce, and a site for business development. Each of these uses has certain preferred conditions-some of which are in conflict. Developing a strategy for the operation and maintenance of the harbor that incorporates these multifaceted needs is crucial for the continued viability of this valuable Georgia water resource.

## Background

This is a particularly important time in the history of the Savannah Harbor. Several recent improvements have affected the hydrodynamics of the harbor. The main ship channel has been widened; the New Cut connector has been closed; and the tide gate has been taken out of operation. In addition, the channel will be deepened from 38 to 42 ft during 1993 and 1994. In order to protect the harbor's environment, all dredging events are carefully planned and performed. To protect certain species, equipment modifications (turtle excluders) or seasonal shutdowns (for striped bass spawning) have been implemented. All of these recent changes have added to the necessity for close coordination among the various parties and interests with responsibilities in the harbor. This is critical if dredging activities are to occur in a timely, efficient, effective, and environmentally sound manner.

The situation related to dredging and disposal in Savannah Harbor is unusual in several ways:

Existing disposal areas are adequate for at least medium-term needs. Most areas undertaking LTMS studies have critical short-term needs, i.e., less than 5 years, (Francingues and Mathis 1990). The situation in Savannah Harbor allows for a truly proactive effort on long-term planning, a 20- to 50-year time frame.

Most of the disposal areas for Savannah Harbor dredging are located in South Carolina (Figure 2). The variations in State laws and regulations and lack of an obvious forum to mediate possible disputes has, in the past, injected an element of greater uncertainty into the disposal planning process.

The local assurer is both capable and motivated. Chatham County is the local assurer

[1] U.S. Army Engineeer District, Savannah; Savannah, GA.

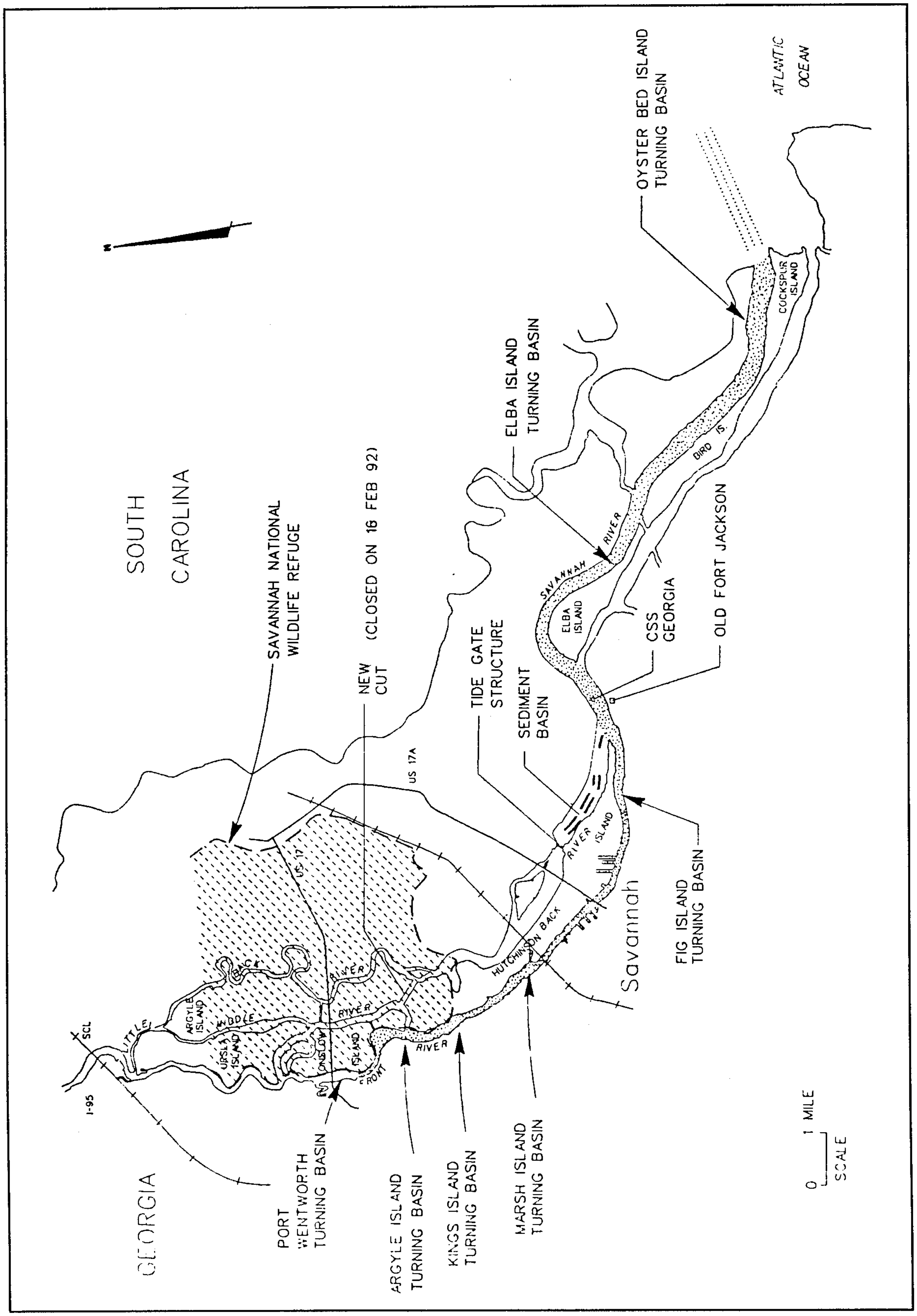


Figure 1. Existing harbor improvements

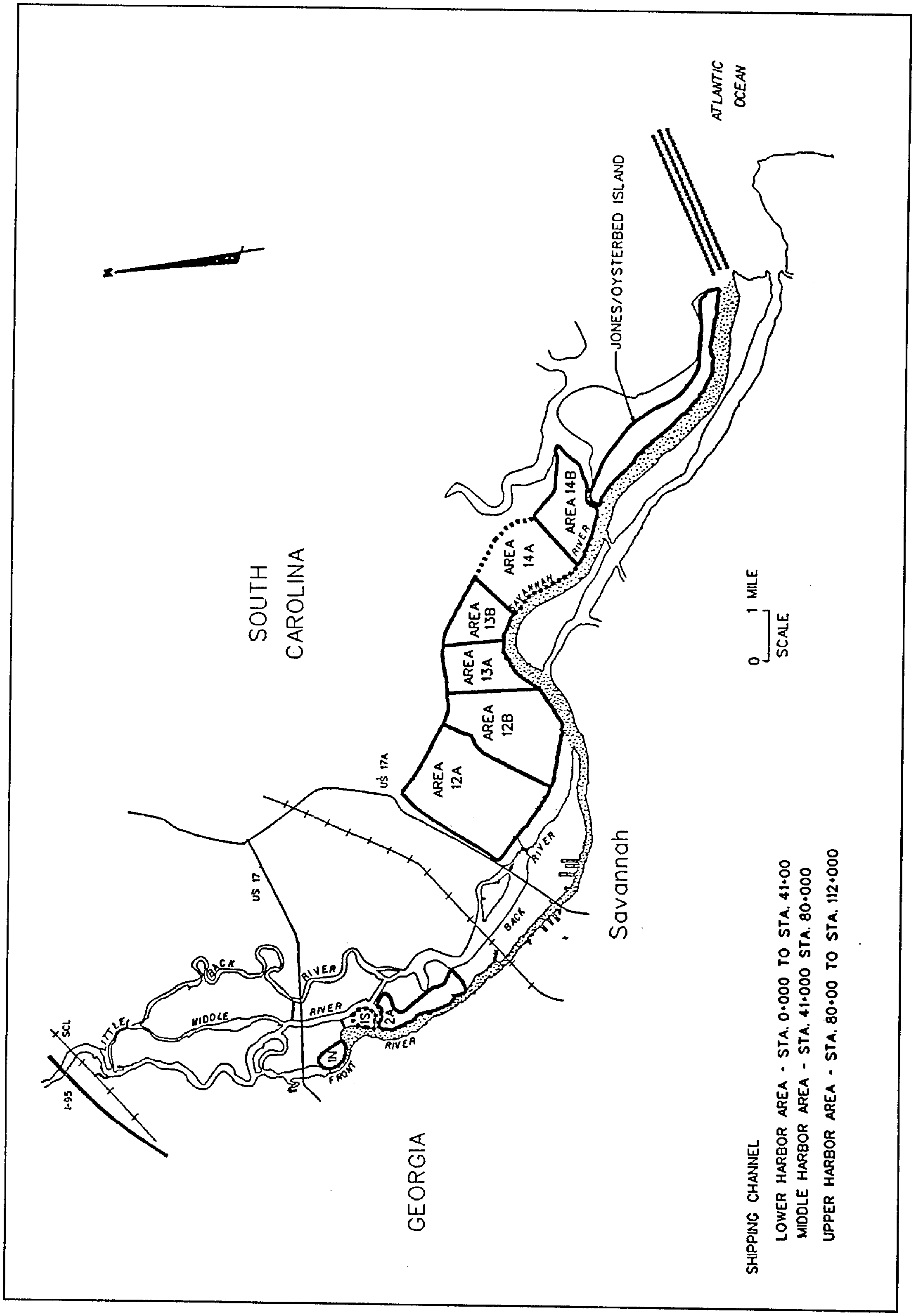


*Figure 2. Savannah River dredged material containment areas*

for the Savannah Harbor project and performs maintenance and mosquito control activities. For large engineering and construction projects, they utilize the expertise of the Georgia Department of Transportation (GADOT). The GADOT is a well-respected engineering organization and is committed to advance planning for disposal area needs as evidenced by their 1989 study "Waterways Dredged Material Containment Areas Study."

## Discussion

### Purpose

The goal of this LTMS effort is to develop the most cost-effective plan agreed to by those involved for maintenance of the Savannah Harbor, including disposal. To accomplish this goal, four major areas must be pursued: Technical (engineering) feasibility of dredging and disposal alternatives; environmental requirements and opportunities; cost effectiveness of various operational strategies; and coordination with interested stakeholders.

### Technical Feasibility

This element includes the physical data collection to establish the changed shoaling patterns in the Savannah Harbor, prediction of quantities of material that will require dredging and disposal, and a schedule for these events. The formulation of alternatives for managing the disposal areas is linked to this base data. This relationship illustrates one of the basic challenges of an LTMS: to integrate the dual needs to have disposal from a dredging event occur at the least-cost (usually closest) area and to maximize the life of the disposal area system, which may require bypassing the closest area to allow drying and consolidation of previously disposed material. Since the responsibility for dredging is Federal and the provision of disposal areas is non-Federal, an operating partnership is essential. The forecasts of dredging and disposal needs will cover a 20-year time frame. A detailed analysis will be done for a 5-year period and repeated for four cycles with adjustments for any items occurring at greater 5-year intervals. Private dredging and disposal needs will be included in this venture.

### Environmental Requirements and Opportunities

The importance of compliance with environmental regulations is accepted and supported by both the Federal sponsor and the local assurer. However, lack of awareness of new requirements or new interpretations of familiar guidelines may result in impacts to timely dredging and disposal operations. In addition, there is a lack of scientific studies on many relevant topics. This may result in either inappropriate restrictions to operations or lack of protection of a sensitive resource. The LTMS will focus on specific topics of concern to Savannah Harbor.

Sampling will be performed to test water quality characteristics at certain locations, and options will be developed for addressing specific issues such as birds nesting at disposal sites. In addition, numerous cultural resources investigations will be performed. These will range from development of mitigation plans for resources currently at risk to a full harbor cultural resources plan. A particularly important task is the development of a compendium and time line of environmental clearances required for dredging and disposal operations. This will ensure that adequate time is incorporated in operational schedules and that the local assurer is aware of all required procedures. Lastly, in conjunction with the engineering and cost-effectiveness elements, beneficial uses such as nearshore berm creation will be evaluated.

### Cost Effectiveness

Federal, State, local, and private entities all pay directly for portions of the maintenance of Savannah Harbor. The LTMS will seek to identify the least-cost scenario for all participants. Among the inputs that will be analyzed are scheduling of dredging, especially

the need for advance maintenance; scheduling of dike raisings; coordination of public and private dredging events; refinement of seasonal restrictions for environmental protection; innovative technologies; and beneficial uses. Accurate input to the cost matrix is essential if a supportable product is to result.

### Coordination

Without the commitment of those with responsibilities in the harbor, the LTMS will be carefully designed, but limited in its usefulness. A three-tier structure has been developed to get input and feedback from impacted parties. Those with major responsibilities for the harbor serve on a small executive group that reviews the policies and framework for the study. A larger work group includes those with ongoing interests in the harbor. This includes resource agencies in Georgia and South Carolina; local government representatives and other Federal agencies. Private interests are involved to ensure that their plans are fully incorporated in the LTMS. They are represented through existing forums such as the Savannah Maritime Council and the Savannah Economic Development Authority. As needed, interest groups will be formed to deal with particular issues in greater depth.

## Conclusions

The development of an LTMS for Savannah Harbor will increase the efficiency of harbor maintenance and disposal efforts by increasing certainty for all parties with responsibilities in the harbor.

Costs for the overall maintenance of the harbor will be lowered as the needs of all parties are coordinated and fewer resources must be devoted to dealing with short-term crises.

The environmental quality of the harbor will be maintained or improved. The data that is gathered will provide a better basis for management decisions, and increased communication may identify new areas for cooperation. The updated (Environmental Impact Statement (EIS) will ensure that all important factors are evaluated and their interactions assessed.

Focusing on and producing specific, interim products to support and further the LTMS effort is important (See product list that follows.)

## Products

- Establishment of Federal Standard for Savannah Harbor in accordance with 22 CFR 334-337.
- Comprehensive Savannah Harbor O&M EIS (Water Quality Certification, Coastal Zone Consistency, BATES, Cultural Resources).
- Long Range Disposal Management Plan (20 years).
- Main Ship Channel Dredging Plan.
- Sediment Basin Dredging Plan.
- Turning Basins Dredging Plan.
- Berthing Areas Dredging Plan.
- Environmental Monitoring Plan.
- Cultural Resources Plan.
- Process to deal with harbor issues.

## Summary

The dredging and disposal operations in Savannah Harbor are good compared with the rest of the country. This enables the LTMS to truly incorporate technical engineering needs, environmental parameters, and cost data to achieve a plan that can be developed by those with varied interests. The process and products produced as a part of the LTMS will provide greater efficiency and thus cost savings (Landin 1992). The LTMS is not a time-limited effort. Its legacy will be a process to deal with harbor issues and a process that will incorporate new data, assess new approaches, and deal with new problems in a proactive,

efficient, and effective manner to the satisfaction of those involved.

## Recommendations

The LTMS should be implemented to its fullest extent and continued as a forum for addressing harbor issues. The overall plan should be reviewed on an annual basis and updated every 5 years or sooner if major events have occurred. National biennial forums such as the meeting held in Baltimore, MD, in 1991 (Francingues, Lamb, and Mathis 1992) should be continued.

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# Hazardous, Toxic, and Radioactive Waste (HTRW) Initial Assessment for the Inner Harbor Navigation Canal Lock Replacement Feasibility Study

*by*
*Julie Z. LeBlanc*[1]

## Introduction

The Inner Harbor Navigation Canal (IHNC) is located in metropolitan New Orleans and connects the Mississippi River, the Mississippi River Gulf Outlet (MRGO), the Gulf Intracoastal Waterway (GIWW), and Lake Pontchartrain for use by barge traffic. The IHNC Lock Replacement Study consisted of replacement and demolition of the existing lock, excavation of a bypass channel into a portion of the industrialized bank of the IHNC along Surekote Road, and dredging and disposal activities. Dredged material is proposed to be used for beneficial use in a nearby wetland setting (see Figure 1).

Concerns in the Hazardous, Toxic, and Radioactive Waste (HTRW) arena have arisen and the following questions must be answered: Is there contamination in the channel or along the industrialized bank of the IHNC (particularly Surekote Road)? Can the sediments and in situ material be used for beneficial use? Will testing be required? Will remediation be required? Through this Initial Assessment process and beyond, we will answer these questions and provide needed solutions. The Hazardous, Toxic, and Radioactive Waste (HTRW) Initial Assessment was conducted in accordance with ER 1165-2-132 (U.S. Army Corps of Engineers 1992) to evaluate the existence or potential for contamination of lands within or affecting the project area. Extensive file research, a land-use history of the area spanning 50 years, and a visual site survey were conducted as part of this Initial Assessment. Because of the industrialized nature of the IHNC and the likelihood of encountering contamination, a Remedial Investigation was conducted in conjunction with the Initial Assessment. This Remedial Investigation included testing and analysis of the water, channel sediments, and soils of the project area.

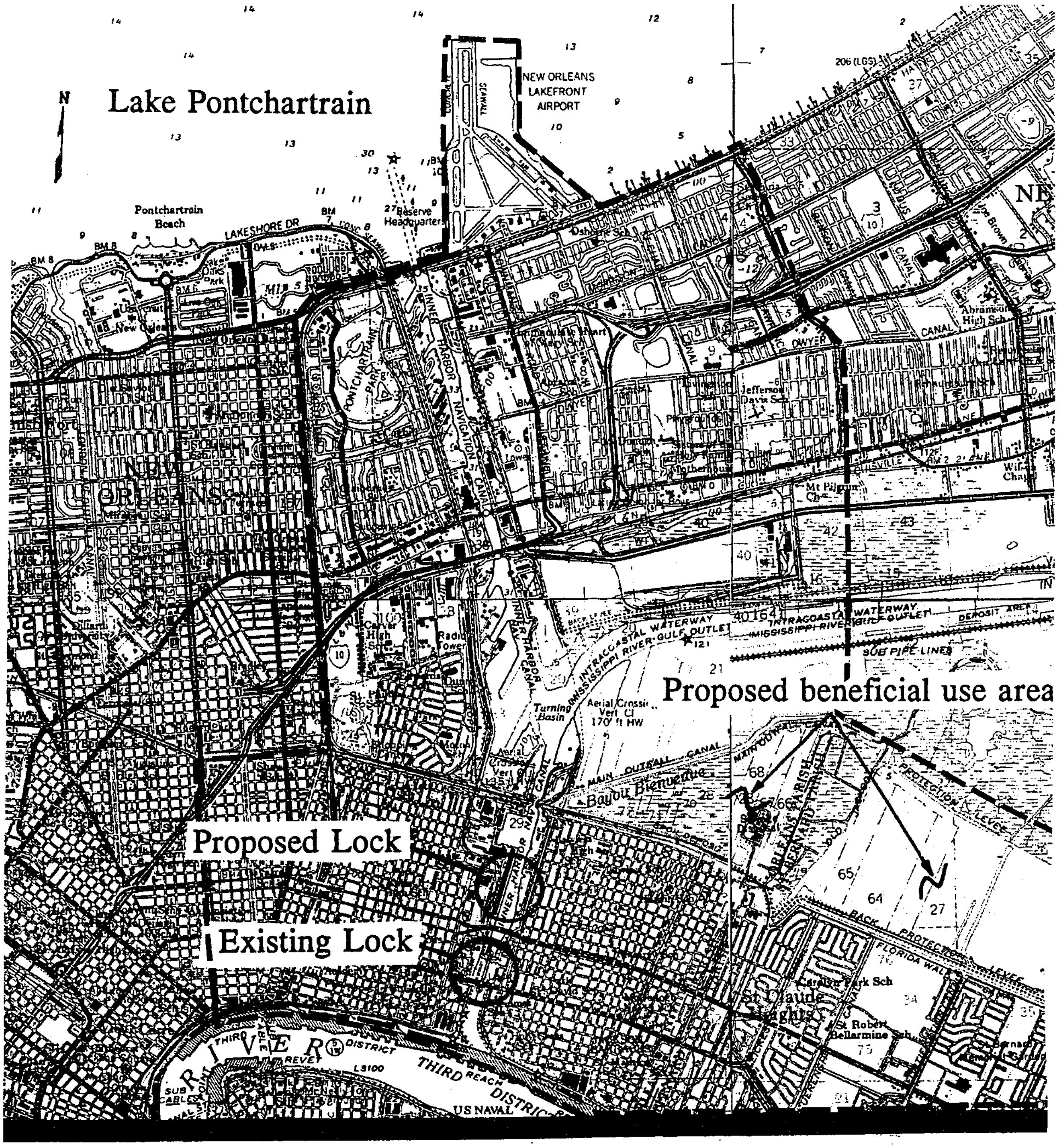
This presentation will explore the procedures, assumptions, and results of the Initial Assessment. A review of all local, State, and Federal agency research for the effort are included. The presentation will focus mainly on the steps and results of the Initial Assessment, but the outcome of testing and analysis conducted for the Remedial Investigation will be touched on briefly. Significant findings from the historic land-use report, aerial photographs, and the visual site survey will be explored.

The primary objective of an HTRW Initial Assessment is to gather and evaluate information regarding the existence or potential for HTRW located in or affecting Corps projects. Optimally, following the ER 1165-2-132 guidance will save the Corps money through avoiding the acquisition of contaminated lands; avoiding project delays during future phases of study or construction; and developing alternatives that avoid known HTRW contamination.

## Conducting the Initial Assessment

Review and research of various agencies were limited, when possible, to sites within zip codes 70117 and 70126 in Orleans Parish and zip code 70032 in St. Bernard Parish.

[1] U.S. Army Engineer District, New Orleans; New Orleans, LA.




Scale: 1" =.98 miles

Legend

— — —Limits of HTRW Initial Assessment

*Figure 1. Proposed Corps of Engineers Lock Replacement*
*Inner Harbor Navigation Canal, New Orleans, LA*

The resultant study area extends 1 to 2 miles from the channel centerline and encompassed land, air, water, sediment, and groundwater considerations. Agency research, land-use history, aerial photograph review, and visual site survey results will be explored in this presentation.

## Agency Research

Agencies where research was conducted include Port of New Orleans, Louisiana Department of Environmental Quality (LDEQ), and the U.S. Environmental Protection Agency (EPA).

The first step was to determine if there currently are any known Superfund sites within the project area. In the State of Louisiana, there are approximately 800 suspected or confirmed hazardous waste sites on the CERCLIS inventory. Of these, 12 were Superfund Sites, otherwise known as NPL sites (National Priorities List). No NPL sites were within the project vicinity. Nine CERCLIS listings were noted to be within the vicinity of the project. None of the nine were proven to have hazardous waste on site, although some are still under investigation. LDEQ's Louisiana Site Remediation Information System (LARIS) was also researched but turned up no positive evidence of HTRW contamination. A site of particular interest was EPA ID# LAD985169663 named "Industrial Canal," which showed a removal action in 1989 by the Coast Guard. This discovery early in the Initial Assessment investigation was a major influence in the decision to do testing in the next phase, Remedial Investigation. Further research through EPA showed that the "site" was not actually a site, but consisted of drums floating in the canal. Subsequent CERCLIS listings do not show this site, although EPA specifically states that once a site is listed on CERCLIS, it is never to be removed, even if the site is deemed nonhazardous. EPA personnel contacted were unable to explain the elimination of the site from the listing. BFI Landfill (EPA ID# LAD980621767) was listed on the CERCLIS but was shown not to handle waste, and a determination of "No Action Needed" was made. The New Orleans Coast Guard Base listing (EPA ID# LA4690310871) is a small quantity generator and was not known to have had incidents, but no final recommendations were noted.

Resource, Conservation, and Recovery Act (RCRA) notifiers are generators, transporters, and/or disposers of hazardous waste who must file for a permit with LDEQ. One hundred seventy-six sites in Orleans and St. Bernard parishes were listed. Eighteen of the investigated notifiers had compliance histories associated with them. All sites that were investigated and subsequently tested by LDEQ proved to be nonhazardous. In general, wastes were shown to be industrial, with the following items noted: spent blast sand, waste oil, waste paints, and solvents. Other noncompliance items were also noted: failure to manifest wastes, failure to mark accumulation dates and types of material, failure to inspect storage area, failure to provide secondary containment, no personnel training, accumulation longer than 90 days, etc. A complaint against Equitable Shipyards on the west bank of the IHNC and north of the proposed lock stated that the company was dumping spent wastes into the canal. No evidence was found to support this claim. Material Transport on the east bank of the IHNC north of the proposed lock admitted that workers routinely dump truck contents on the ground during cleaning processes. Also of interest was the fact that numerous types of wastes were received at the site, but no record of final destinations were recorded. LDEQ testing conducted at Material Transport failed to identify waste considered hazardous.

LDEQ Emergency Response Section maintains a log of spills and citizen complaints. During the time period from 1985 through February 1993, there were 536 spills in Orleans Parish and 295 spills in St. Bernard Parish. Of the 831 total spills, 229 were within the project vicinity. These 229 spills were directly along the Industrial Canal and were considered a major threat to the project area.

Twenty-six percent of the spills in the project vicinity were recorded for 3501 France Road, which is operated by New Orleans Marine Contractors, approximately 0.8 miles north of Florida Avenue on the west bank of the IHNC. Seventeen percent of the spills were logged for CSX Railroad located approximately 1 mile east of the IHNC. Eleven percent of the spills were recorded for Southern Railway Systems located at 2101 St. Ferdinand Street, not directly on the canal bank. Eight percent were recorded for 2700 France Road, directly on the westbank of the IHNC north of Florida Avenue at the France Road Terminal operated by the Port of New Orleans. Two spills were logged at 2100 Surekote Road operated by Mayer Yacht and Distributors Oil Company. These two spills were of greater concern than the others because they are in the area to be excavated for the bypass channel. One hundred and six citizen complaints were taken during the period spanning 1988 through February 1993. Of these, nine were within the project vicinity. No evidence of hazardous waste contamination was found at eight of the sites. A complaint for 1910 Surekote Road, Saucer Marine Corporation, revealed blast sand piles, oil saturated soils, and 55-gal drums. LDEQ-mandated Toxic Characteristic Leachate Procedure (TCLP) analysis showed suspected problems were below hazardous levels, and the waste was classified as industrial.

The LDEQ Underground Storage Tank (UST) Division shows 208 registered USTs owned by 79 different companies in the study area. Most USTs contain petroleum hydrocarbon products and are a potential source of soil and groundwater contamination. This number shows registered USTs and does not count illegal tanks or tanks installed or abandoned prior to LDEQ record keeping. Of the 79 companies having USTs, LDEQ research revealed leaking tanks or mandated quarterly monitoring at 13 of the sites (for a total of 16 percent).

A search of LDEQ's Ground Water Protection Divisions files uncovered only one of nine sites on their listing for Orleans and St. Bernard parishes having potential contamination within the project vicinity. This site is CSX Transportation on Almonaster Avenue and currently is under assessment for diesel contamination. It is approximately 0.5 mile north of the GIWW, and groundwater flow is believed to be toward the south. Remedial studies show two plumes of total napthalenes and polyaromatic hydrocarbons migrating slowly southward.

LDEQ Air Quality Compliance Division maintains databases of air emissions in the State. Compliance Data System (CDS) is a listing of permitted sites that includes a listing of enforcement actions. The CDS system lists 41 facilities in the project vicinity that are permitted to release air toxins; 10 of these facilities (or 24 percent) have some form of enforcement or formal inquiry action against them. The time frame evaluated was from 1989 to March 1993. LDEQ Air Quality Regulatory Division maintains the Toxic Emissions Data Inventory (TEDI) database. The TEDI database is a listing of actual releases of 100 toxic compounds by emission point; only sites with more than 10 tons of one compound or 25 tons of a combination of compounds are listed. Equitable/Halter of 4325 France Road was listed with total toxins emissions of 211,397 lb per year.

Discussions with the Port of New Orleans personnel were also important because they are the majority landowner along the IHNC. Close contact with the Port's Environmental Manager was essential in developing a plan of attack to determine contamination directly in the path of the project. Providing access to the property for site visits and full cooperation during our testing activities during the Remedial Investigation made it easier to conduct our investigation.

## Land-Use History

A detailed description of residential, commercial, and industrial land uses in the project area was documented from 1940 to present by R. Christopher Goodwin and Associates (1992). The IHNC originally opened in 1923 and

showed dramatic industrial expansion during the 1960s and 1970s. The Land Use History was especially helpful in identifying previous land uses, especially where the proposed bypass channel is to be constructed. The site uses along the IHNC were mainly navigation and cargo type industries that historically utilize a variety of hazardous materials in day-to-day operations. Main uses along Surekote Road were towing of vessels, maintenance of vessels, transport, metal fabricators, and fueling facilities.

### Aerial Photographs Review

As a part of the Initial Assessment, aerial photographs from 1933, 1950, 1960, 1973, and 1981 were used to verify the dates companies appeared at a certain site and in some instances to verify site conditions. The aerials were particularly valuable in determining where testing should be conducted on presently abandoned sites by locating potential "hot spots" (for instance, haphazardly stored 55-gal drums were identified in an aerial photograph where now there is bare ground). The height of the activity in this area corresponded to the 1981 aerial when approximately 100 percent of the sites were occupied. Today, with a less than 50-percent occupation rate of Surekote Road businesses, insight can be gained regarding what the area was like in the past.

### Visual Site Survey

Cursory site visits to the east bank of the IHNC along Surekote Road were conducted by seven Corps personnel and two Port personnel, revealing many abandoned sites and/or sites that warranted further investigation. No hard evidence of contamination was uncovered, but a plentitude of potential was identified. Examples of what was discovered were abandoned, unlabeled, or open 55-gal drums (some in poor condition), stressed vegetation, possible asbestos, numerous locations of oil-saturated soils, and rusted storage tanks in or near the canal. The existing lock, Galvez Street Wharf and U.S. Coast Guard facilities on the west bank of the IHNC were also visited. Conditions on the west side of the canal were notably better.

### Conclusions and Recommendations of the Initial Assessment

Throughout the recommended steps of ER 1165-2-132, no definite hazardous waste contamination was noted but an abundance of potential existed. Upon completion of this phase, the Remedial Investigation was already full-swing with additional recommendations for testing stemming from this Initial Assessment. This Initial Assessment would prove an invaluable tool in the event contamination was discovered by identifying potentially responsible parties (PRPs), contamination sources, and extent of contamination.

## The Next Step: Remedial Investigation

Field investigation, sampling, and analytical testing were conducted by the Corps to generate baseline chemical data at the project site. Testing consideration was given to canal bottom sediment, in situ soil, and groundwater. As of this writing, 11 bottom sediment, 149 soil, and 25 groundwater samples were collected and analyzed for various hazardous and toxic constituents. In addition, a passive soil gas survey and shallow groundwater investigations along Surekote Road were performed.

Bottom sediment samples from the canal showed detectable total and TCLP concentrations of some metals and herbicides, and below detection limits for all other constituents. All levels were below the hazardous thresholds established by EPA.

The soil and groundwater samples from along Surekote Road were contaminated from the surface until depths of approximately 5 ft with metals, volatile organic compounds, and base/neutral semivolatile organic compounds. Chlorinated hydrocarbons, pesticides, and asbestos were also detected. All pollutants in soil have detectable bulk concentration levels below the 1990 action levels proposed by

EPA. TCLP and ignitability tests performed on soil samples yielded results that were below the regulatory toxicity limits and ignitability criteria set by EPA.

The analytical data indicate that the soils to be excavated from the east bank were generally acceptable for disposal at an industrial landfill. If the top 5 ft of soil was excavated for land disposal, preliminary estimates yield about 14,000 cu yd of soil with lead concentrations of greater than 100 mg/kg, 8,250 cu yd of soil contaminated saturated with used oil, and 3,820 cu yd of soil contaminated with petroleum fuel that may require special handling or treatment prior to disposal. An unestimated volume of nonaqueous petroleum rich liquids at the bottom of oil-saturated soils may require collection and proper disposal prior to excavation of the soils. In addition, an unestimated volume of the groundwater may also require treatment.

In general, the results of our Initial Assessment and the tentative results of our Remedial Investigation show that only a limited amount of the in situ soil will need to be hauled to an industrial landfill, the remaining is suitable for disposal or use as a fill material. No hazardous wastes were discovered as a result of the Initial Assessment or Remedial Investigation. Considering the type of land use and the history of poor or nonexistent management of wastes, this was surprising.

## Where Do We Go From Here?

This study was the District's first carried through the Remedial Investigation stage under ER 1165-2-132 guidance. The Feasibility Study is currently awaiting submittal and review, and there still is much left to do. Testing must be conducted on the west bank of the IHNC, and LDEQ must be approached to approve our testing, analysis, results, and plan of action.

Although the soils were generally below published Federal numerical criteria, LDEQ may have special concerns. Consultations with other Federal regulatory agencies and LDEQ need to be initiated to help guide future investigations, resolve concerns on public health and environmental risks associated with soil and sediment excavation at the site, and explore acceptable disposal and treatment schemes.

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# Hazardous, Toxic, and Radioactive Waste Initial Assessment for a Flood Control Project in an Urban Watershed

*by*
*Cheryl G. Peyton*[1]

## Introduction

In June of 1992, ER 1165-2-132 became official, requiring, among other things, that a Hazardous, Toxic, and Radioactive Waste (HTRW) Initial Assessment (IA) be performed for every Corps of Engineers Civil Works project during the reconnaissance phase of the project. In addition, the American Society for Testing and Materials (ASTM) has issued two documents relating to HTRW IAs, "Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process" (E 1527-93), and "Standard Practice for Environmental Site Assessments: Transaction Screen Process" (E 1528-93). Such guidance for both the Corps of Engineers and private industry is driven by the liabilities associated with worker safety and the innocent landowner defense.

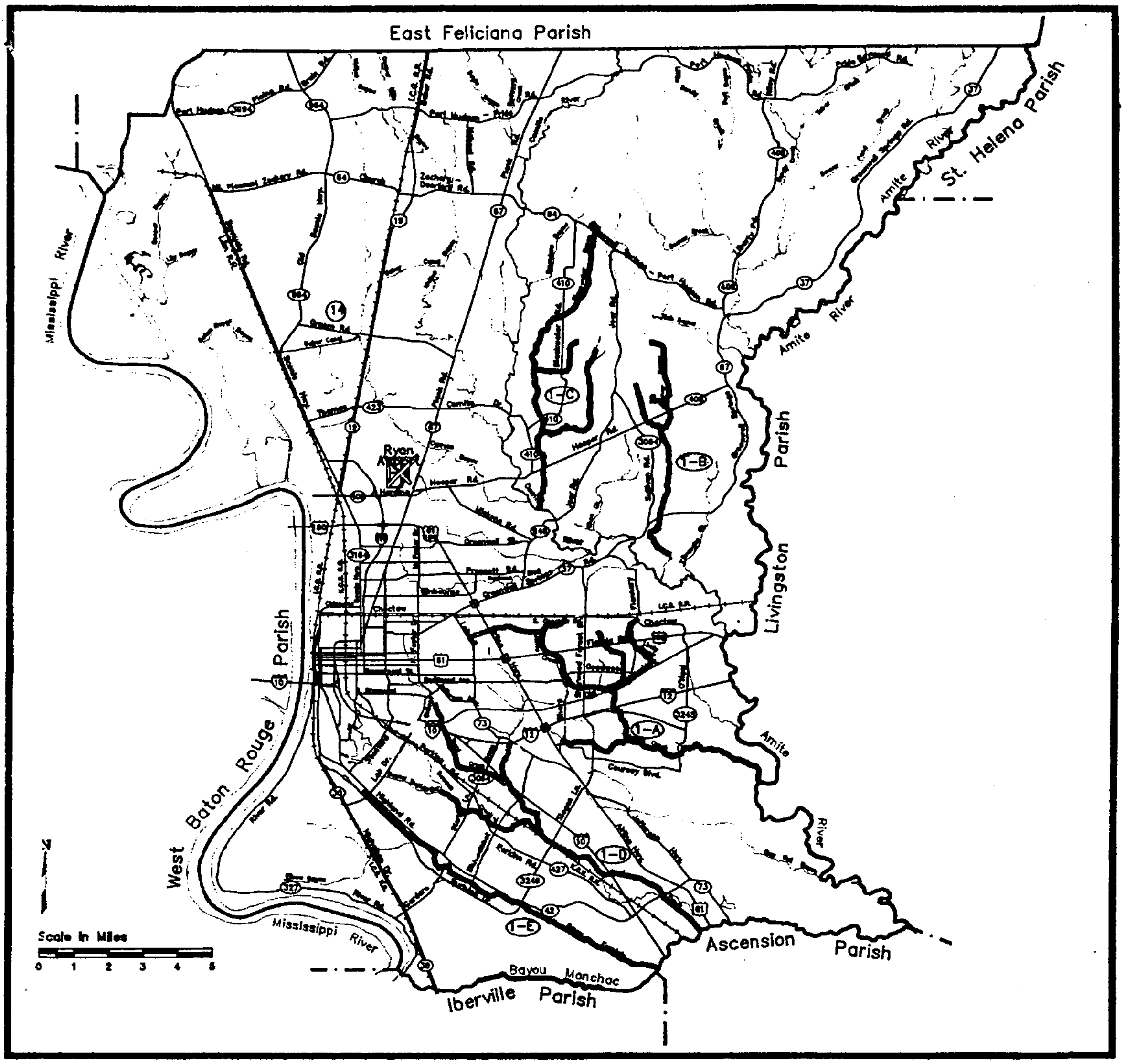
## East Baton Rouge Parish Project

An excellent example of the application of this guidance to a Corps Civil Works project is the Amite River and Tributaries Flood Control Feasibility Studies project, located in the State of Louisiana. It is a large project that is broken down into numerous smaller projects, one of that is East Baton Rouge Parish (see Figure 1). The study contains five tributary systems that drain primarily urban watersheds. Channel improvements are proposed for approximately 73 miles of these tributaries. Because ER 1165-2-132 is retroactive and the East Baton Rouge Parish project had proceeded to the feasibility phase before the regulation became effective, the HTRW IA for East Baton Rouge Parish was conducted during the feasibility stage of the project, rather than the reconnaissance phase. The East Baton Rouge Parish HTRW study was significant because it is in an urban watershed and it was the first IA conducted under the new regulation by the U.S. Army Engineer District, New Orleans.

## HTRW IA

The regulation requires that the IA include a study of existing and past land uses (Land Use History), a review of the U.S. Environmental Protection Agency (EPA), State, and local regulatory or response agency records (Regulatory Agency Review), and a visual survey of the site and vicinity (Visual Site Survey). A section regarding Site Characterization and Geology is also included in IAs to assist in analyzing the impacts of contamination. Contrary to popular belief, the Visual Site Survey was not the most prolific source of information. This study revealed that a thorough records search at regulatory and response agencies including EPA, Louisiana Department of Environmental Quality (LDEQ), Louisiana Department of Natural Resources (LDNR), Louisiana State Police, and the Baton Rouge Fire Department yielded far more pertinent information than either the Land Use History or the Visual Site Survey.

[1] U.S. Army Engineer District, New Orleans; New Orleans, LA.




Proposed
Corps of Engineers
Flood Control and
Drainage Improvement Projects
East Baton Rouge Parish Tributaries

Legend:

Proposed Corps of Engineers Projects

Corps of Engineers Flood Control Improvements

1-A Jones Creek and Tributaries
1-B Beaver Bayou and Tributaries
1-C Blackwater Bayou and Tributaries
1-D Ward Creek and Tributaries
1-E Bayou Fountain and Tributaries

*Figure 1. East Baton Rouge Parish project*

## Characteristics Unique to an Urban Watershed

The urban nature of the East Baton Rouge Parish project presented two primary problems. First, the site is a series of proposed channel improvements; thus defining the area of influence was difficult. Second, the project is in an urban watershed; thus the shear number of potential concerns was extraordinary. The challenges peculiar to this project were determining the general project vicinity, processing the vast quantity of data available regarding HTRW activities in the project vicinity, and determining that locations were of significant concern.

### Project Vicinity

Industry standard has been to evaluate potential HTRW concerns on the site in question for direct contamination as well as locations within approximately a 1-mile radius of the site for potential contamination from offsite. The 1-mile radius loosely defines the vicinity of the project. ASTM E 1527 uses the term "approximate minimum search distance," that is more clearly defined as being measured from the nearest property boundary. The document states that "this term is used in lieu of radius to include irregularly shaped properties." The actual distance that is included is dependant on soil, groundwater, surface water, and drainage conditions. It may actually be more or less than 1 mile. A vicinity of 5 miles or more may be appropriate for air contamination concerns.

The concept of the vicinity or approximate minimum search distance works well for nicely defined, squarish plots. Unfortunately, the site in question for the East Baton Rouge Parish HTRW study consisted of 73 miles of five different channels and their associated tributaries. Obviously, there were no HTRW generators within the channel itself, and most of the concern was over potential contamination entering the project boundaries from offsite. For this project, the vicinity was defined as that area approximately one-half a mile to a mile from the project boundary. Thus, the shape appeared to be something of a multi-fingered glove shape for each channel, rather than a balloon that encompassed the whole system. This made picking out those sites that fell into the vicinity a little more difficult, but reduced the total number of sites that required further evaluation, thus reducing the total study time.

### Quantity of Data

Even with this time-saving concept, however, the greatest surprise in the study was the shear number of concerns that required further evaluation. For example, there are over 1,000 facilities registered as required under the Resource Conservation and Recovery Act (RCRA) and approximately 1,600 registered active underground storage tanks in East Baton Rouge Parish. In addition, there have been more than 1,000 Hazardous Materials Emergency Response incidents in the parish since 1985. In total, more than 6,000 locations and incidents were revealed for further study during the agency review. Every incident and item revealed during the agency review required attention to determine (a) if the site was within the vicinity of the project and (b) if it was a potential contamination concern. The sites/incidents that met these two criteria provided the critical information needed for the next phase; namely, what to test for and where. The agency review and subsequent evaluation was the most time-consuming and costly activity of the entire project. As mentioned previously, however, it revealed the most useful information.

### Common Urban Concerns

The most common types of concerns revealed in the study included petroleum hydrocarbon-associated industries (gasoline filling stations, automotive service stations, oil and gas exploration, etc.); dry cleaners and laundries; medical facilities; photography-associated industries; landfills; government installations; and HTRW handlers (laboratories, transporters, storers, disposers, etc.). These concerns

seemed fairly typical of any urban setting. The following are brief discussions of each of these types of activities and why they are of concern.

- **Petroleum Hydrocarbon-Associated Industries**. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) excludes petroleum hydrocarbons from the definition of hazardous substance, saying

  > The term does not include petroleum, including crude oil or any fraction thereof that is not otherwise specifically listed or designated as a hazardous substance under subparagraphs (A) through (F) of this paragraph, and the term does not include natural gas, natural gas liquids, liquified natural gas or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas), (Section 101 (14)).

  However, many of the constituents of gasoline and other petroleum products (eg., benzene, ethylbenzene, toluene, and xylene) are considered hazardous and are regulated. The ruling is akin to saying that chocolate cake is not fattening, however the sugar and oil in the chocolate cake is. Furthermore, many of the byproducts of the oil and gas industry are also of concern. The drilling of oil and gas as well as the transport of the products through pipelines creates sludges. These sludges, from deep within the earth, contain low levels of natural radioactivity. Thus, they are in the category of Naturally Occurring Radioactive Materials (NORM). Over time, these sludges can become concentrated, so that what was once low level becomes a concern. At the time of this writing, the State of Louisiana has not adopted criteria for the levels of NORM that are hazardous. However, equipment registering radiation levels of more than 30 picocuries must be registered. Thus, because of the associated concerns, businesses associated with petroleum hydrocarbons are included in IAs for further evaluation, even though petroleum products are not specifically labeled hazardous.

  Materials generally associated with auto service, repair, and salvage include abrasives, acids, adhesives and removers, alkalis, antifreeze, battery acids, brake fluids, brake linings, cleaners, detergents, diesel fuel, epoxy resins, flame retardants, gasoline, gasoline additives, heating oil, hydraulic fluids, lubricants, oils, paint removers, paint thinners, paints, petroleum fuels, rubber, solders, solvents, thinners, transmission fluids, and waste oils. Raw materials, intermediate products, final products, and waste products generated in association with auto service and repair include asbestos, heavy metals, hydrochloric acid, lead, and tin. Other associated materials include benzene, bromodichloromethane, bromoform, butane, carbon tetrachloride, dichlorobenzene, dichloroethane, dichloroethene, dichloromethane, ethyl benzene, hexane, methyl tertiary butyl ether, naphthalene, perchloroethene, toluene, trichloroethane, trichloroethene, and xylenes.

  The types of chemical materials generally associated with petroleum exploration and production include acids, alkalis, brine, crude oil, herbicides, lubricants, paints, paraffin, pesticides, petroleum hydrocarbons, and solvents. Raw materials, intermediate products, final products, and waste products generated during manufacture and use include barium, benzene, bromide, calcium, calcium oxide, heavy metals, hydrogen sulfide, iodide, polychlorinated biphenyls, polynuclear aromatic hydrocarbons, potassium, sodium chloride, and zinc. Other associated materials include benzene, ethyl benzene, hydrogen chloride, toluene, and xylenes.

  Gas exploration and processing raw materials, intermediate products, final products, and waste products generated during

manufacture and use include benzene, mercaptons, and phenols. Gas exploration also involves beryllium that can be a naturally occurring radioactive material, and thorium, which is always a naturally occurring radioactive material.

- **Dry Cleaners and Laundries.** The most common concern associated with dry cleaners is the dry cleaning fluid, tetrachloroethylene (also known as tetrachlorethylene, perchlorethylene, perchloroethylene, and perk). Before the hazards of this substance were known, many cleaners simply disposed of the used chemical out the back door. As a result, many dry cleaners have a substantial soil contamination problem around their facilities today.

  General types of materials associated with dry cleaning and laundries include alkalis, bactericides, bleaches, brighteners, detergents, enzymes, fungicides, sizing, soaps, solvents, surfactants, turpentine, and waterproofing. Other associated materials include acetic acid, ammonia, amyl acetate, benzene, carbon disulfide, carbon tetrachloride, chlorinated lime, chlorine, dichloroethane, dichloroethyl ether, dichloroethene, ethyl ether, ethylene chlorohydrin, ethylene glycol ether, formic acid, methanol, nitrobenzene, oxalic acid, perchloroethene, polynuclear aromatic hydrocarbons, propylene dichloride, sodium hydroxide, stoddard solvents, tetrachloroethane, tetrachloroethene, trichloroethane, and trichloroethene.

- **Medical, Dental, and Veterinary Facilities.** Medical, dental, and veterinary facilities include hospitals, doctor's offices, dentist's offices and laboratories, and veterinary offices and clinics. The activities that cause greatest concerns are associated with taking and developing X-rays, other radiological treatments, and biological wastes. Surprisingly, silver is the hazardous substance that these facilities most often list on their RCRA notification forms. Silver is used in developing X-rays. If it is ingested, it can cause a condition known as argyria that is a permanent gray discoloration of the skin and eyes.

  Materials generally associated with medical, dental, and veterinary facilities include adhesives and removers, amalgams, anesthetics, antiseptics, dental alloys, deodorants, detergents, diesel fuel, disinfectants, drugs, gasoline, heating oil, pesticides, resins, rubber, soaps, stains, and waxes. Raw materials, intermediate products, final products, and waste products generated include aniline dyes, bacteria, benzol, chromium, ethyl chloride, eugenol, formaldehyde, germanium, gold, heavy metals, mercury, osmium tetroxide, picric acid, platinum, propyl alcohol, silver, tetrachloroethene, toluene, and viruses. Other associated materials include dioxane, ethyl alcohol, and xylenes. Also included are radiological hazards and materials.

- **Photography-Associated Industries.** Industries associated with photography are also generators of silver wastes. General types of materials associated with the manufacture and use of photographic chemicals, films, papers and plates include acetates, acids, alkalis, and turpentine. Raw materials, intermediate products, final products, and waste products generated during the manufacture and use include acetaldehyde, acetic acid, amyl alcohol, aniline, benzyl chloride, boron, cadmium, chromates, chromium, dibromoethane, dichloroethane, dinitrophenol, formaldehyde, hydrazine and derivatives, hydroquinones, ketones, mercury, methyl alcohol, methylaminoethanol, methyl para-aminophenol sulfate, n-Butyl alcohol, n-Butylamine, para-aminophenol, paraformaldehyde, paraphenylenediamines, picric acids, quinone, selenium, silver, sodium hydroxide, sodium hypochlorite, sodium sulfide, uranium, and vanadium. Other associated materials include hydrogen chloride and acetic anhydride.

- **Landfills**. Landfills are the most complex of all HTRW concerns. Comprehensive lists of materials associated with landfills are not possible because of the great variety of constituents. However, methane is a gas that is generally associated with the decomposition occurring in landfills and is almost always present. Landfills may contain household wastes, including cleaners, automotive products, garden products, pool products, and human and animal biological wastes (eg., disposable diapers and cat litter); medical wastes; industrial wastes; and HTRW. In addition, chemicals and hazards in the landfill have the potential of combining with other chemicals present to form new hazards. Every type of hazard imaginable is possible in conjunction with landfills.

- **Formerly Used Defense Sites**. Various municipal facilities are often built on Formerly Used Defense Sites (FUDS). Some of the most common are airports, industrial parks, and subdivisions. The hazards that may remain on a FUDS are dependent on the original use. Since military sites are often "mini-cities," they contain many of the other hazards already mentioned, including gasoline, heating oil, and other petroleum hydrocarbons, medical and dental wastes, landfills, etc. In addition, these sites also have additional hazards associated with military operations, such as sandblasting operations, chemical weaponry, and ordnance explosive wastes.

  Standard military closure procedure 40 or 50 years ago seemed to be to leave underground items in place and bury what would not be surplused or otherwise removed. As a result, today, many abandoned Underground Storage Tanks (USTs) are leaking. Other buried materials are creating additional potential problems. Many of the FUDS contained practice bombing ranges and ground artillery ranges. When these sites were closed, they were generally searched thoroughly. Nevertheless, even the most thorough search cannot locate every remaining round, especially those that are buried or partially buried. Through the course of time, the earth has shifted, and much of what was once buried or missed during the search now lies on or near the surface. It is not uncommon to find old unexploded ordnance on FUDS. Even though much of the ordnance remaining was for practice, it still contains a charge and can be deadly.

- **HTRW Industries**. Because the HTRW field has grown so much in the last few years, support industries have also grown. These may include transporters of hazardous wastes; treaters, storers, and disposers (TSDs) of hazardous wastes; environmental testing laboratories; and environmental engineering companies. Most operate within the purview of the law and carry on in a safe and efficient manner. Some, however, do not. All are subject to occasional spills and accidents, as is any other business that deals with HTRW. The types of materials and hazards that may be encountered is dependent on the clientele of the business and is varied as the HTRW industry itself.

## Conclusions

Thus, performing an HTRW IA in an urbanized area has a few common hazards. Any number of other hazards may also be present, and only a qualified environmental professional can adequately evaluate what they may be. The East Baton Rouge Parish HTRW IA was further complicated by the odd "shape" of the project vicinity. Once the project vicinity was determined, however, the IA became routine, with only the vast amount of data being a concern. Perhaps, the most difficult part of the process and dealing with the new regulation is convincing others in the organization that the time and effort spent on a complete and thorough IA as dictated by the ER 1165-2-132 is time and money well spent. The process can be costly initially; however, detecting a contamination problem early can save millions in remediation fees or redesign costs later.

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# Demonstration of Equipment for Dredging Contaminated Sediments at Buffalo River, Buffalo, New York

*by*

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## Introduction

Contaminated sediments exist in many United States waterways. Dredging is often a convenient and economical method of removing these sediments. However, significant concern exists over the potential environmental effects resulting from the localized sediment resuspension and contaminant release that may occur during the removal operation. Most contaminants are attracted to fine-grained sediment particles (Zappi and Hayes 1991). When the sediments are disturbed, such as by dredging, contaminants may be transferred to the water column through resuspension of the sediments, dispersal of interstitial water, or desorption from the resuspended solids. Generally, almost all the contaminants transferred to the water column are due to the resuspension of solids. Therefore, the release of contaminants can be reduced by limiting the resuspension of solids during the dredging and disposal operations (Palermo and Pankow 1988).

The 1992 Energy and Water Development Appropriations Bill directed the U.S. Army Corps of Engineers to conduct a demonstration of dredging methods in the Buffalo River (Figures 1 and 2). Existing authorities required that dredging operations for the Buffalo River demonstration take place within the navigation channel and the navigation channel side-slopes. In addition, the U.S. Environmental Protection Agency's (USEPA) Great Lakes National Program Office (GLNPO) provided support to the U.S. Army Engineer District, Buffalo, to initiate planning, engineering, and design work.

## Description of the Buffalo River

The Buffalo River watershed is located in the west central portion of New York State (Figure 1). The Buffalo River channel, to the upstream limit of the Federal project, and the Buffalo Ship Canal, for a distance of approximately 1 mile upstream from its confluence with the Buffalo River, have a project depth of 22 ft in soft material and 23 ft in hard material. However, the lower portion of the Buffalo River and the Buffalo Ship Canal are maintained to a depth of 22 ft, while the upper portion of the Buffalo River is maintained to a depth of 21 ft (Figure 2). Channel widths generally are 150 ft in the Buffalo River and 125 ft in the Buffalo Ship Canal, without dredging closer than 25 ft to dock lines except at Channel bends. In recent years, the river has been dredged every other year with the dredge quantity in the 100,000- to 150,00-cu yd range.

The Buffalo River and its sediments have been polluted by past industrial and municipal discharges. Metals and cyanides in the sediment prevent open-lake disposal of sediments dredged from the river. The contaminated sediments are known to be one of the sources of pollutants causing impairments to the river. Since 1973, the International Joint Commission (IJC) (a bi-national commission advising governments on issues involving the boundary waters between Canada and the United States)

[1] U.S. Army Engineer District, Buffalo; Buffalo, NY.

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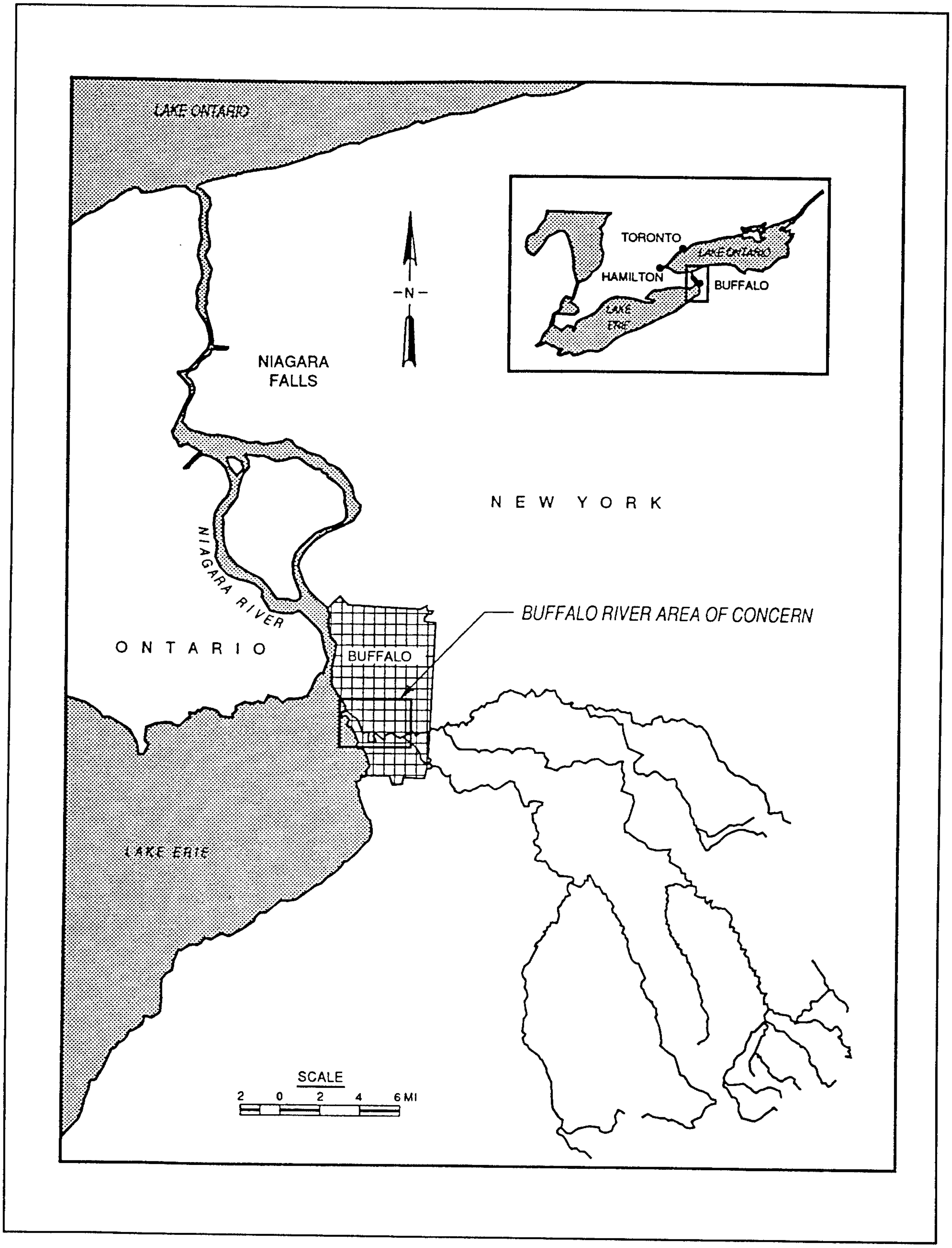


*Figure 1. Regional map*

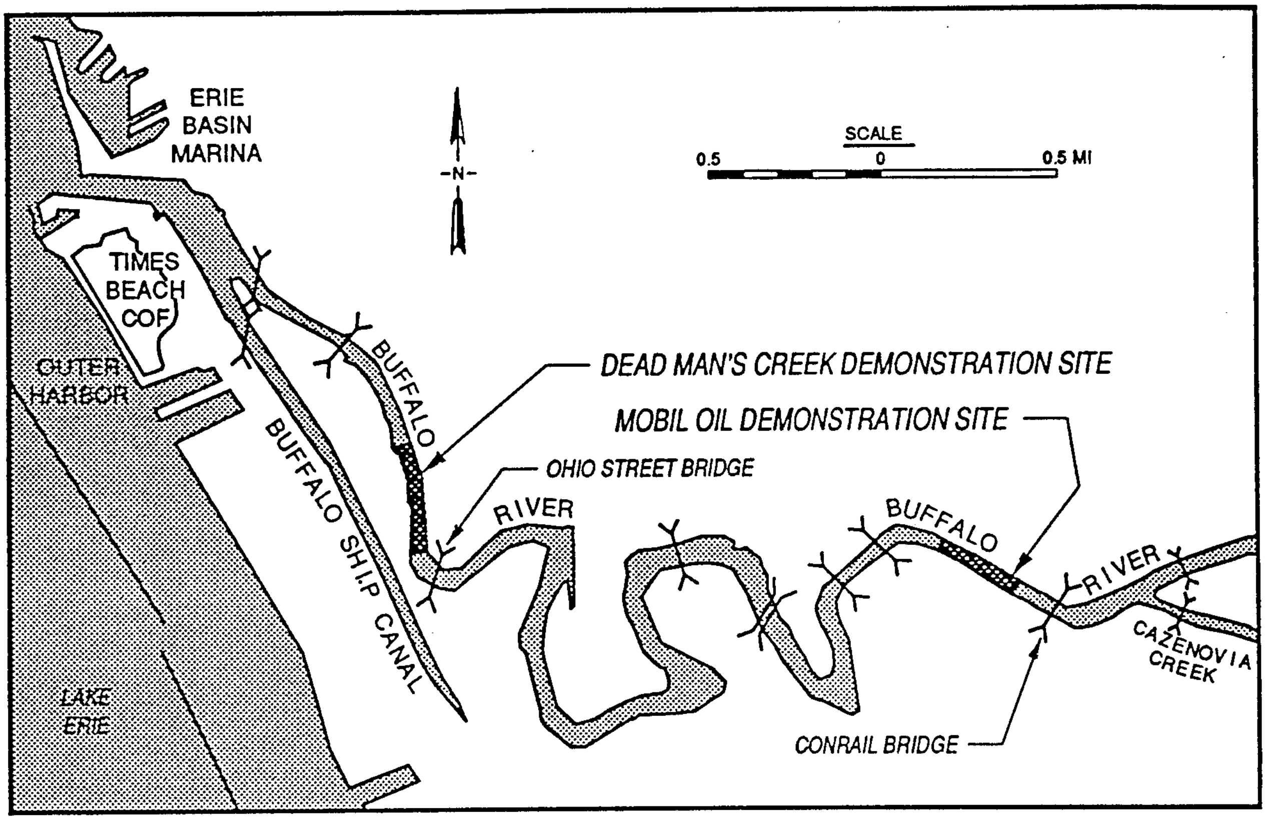


*Figure 2. Vicinity map*

has identified 43 Areas of Concern (AOCs) on the Great Lakes where the poor quality of water impairs its use or local environmental standards are not being met. The Buffalo River has been identified as one of the 43 AOCs on the Great Lakes. The IJC has developed a program to encourage the restoration of these sites and is implementing this strategy through the development of Remedial Action Plans for each AOC.

The USEPA sampled along the Buffalo River each year from 1989 through 1992. Based on available sediment sampling and analysis data, there are portions of the Buffalo River where the sediments generally have higher concentrations of contaminants, PAHs, and heavy metals than other portions of the river. Using available information from USEPA's 1990 sampling and analysis programs, five areas of the Buffalo River (Dry Dock Cove, Dead Man's Creek, Hamburg Street, Blue Tower Turning Basin, and Mobil Oil Refinery) were specified as potential dredging areas. These areas were proposed as possible sites for a dredging demonstration because contaminant concentrations in the sediments were somewhat elevated (though the sediments were not toxic or hazardous) and because these areas presented an opportunity to clean up portions of the Buffalo River during the dredging demonstration. Additional investigations of the five identified areas were conducted by the USEPA's Large Lakes Research Station of Grosse Ile, MI, during August 1991. Sediment cores were collected using the USEPA's floating plant and vibracore unit. The cores were split, photographed, characterized, and sampled in the field. The samples were analyzed with the results of the analyses used to map the horizontal and vertical distribution of contaminants. The results of the sediment characterization of these five areas were made available in March 1992 and were used to finalize the dredging demonstration plan. After analysis of the available data and extensive coordination with local interest groups, it was decided

that the demonstration dredging would take place at the Dead Man's Creek and Mobil Oil areas (Figure 2). These areas appeared to present the best opportunity to remove contaminated sediments while leaving less contaminated sediments exposed, an important consideration for any "environmental" dredging.

## Coordination and Planning

In fiscal year 1991, the United States Congress appropriated $600,000 to the USEPA for clean up work on the Buffalo River. Starting in December 1990, the USEPA GLNPO coordinated with Region II USEPA, the New York State Department of Environmental Conservation (NYSDEC), Erie County, the U.S. Army Engineer Division, North Central, the Buffalo District, and the Buffalo River Remediation Action Committee (RAC) on how to best utilize this funding. Ultimately, it was determined that $100,000 of this funding would be provided to the Buffalo District to initiate Pre-construction and Engineering and Design (PED) work that included coordination efforts associated with the dredging demonstration, analysis of structures and banks along the Buffalo River and preparation of a work plan, environmental assessment, and plans and specifications.

PED work was initiated by the Buffalo District in December 1991, when work was started on the "Work Plan for Demonstration Dredging of Contaminated Sediments at the Buffalo River." This plan, approved by Headquarters, U.S. Army Corps of Engineers (HQUSACE), in April 1992, described the purpose and objectives of the demonstration, provided a description of the Buffalo River and its sediment, detailed coordination efforts, and briefly described the proposed demonstration and the activities that must be completed before the demonstration could take place (U.S. Army Enginner District, Buffalo 1992).

Preparation of plans and specifications (P&S) was started in early 1992. After some discussion within the Buffalo District, it was decided that the demonstration dredging requirements would be made a part of the plans and specifications for the maintenance dredging performed on the Buffalo River in 1992. It was anticipated that some of the same equipment could be used for both dredging projects, saving significantly on mobilization and demobilization costs. However, there also was fear that forcing a contractor to complete both dredging projects may artificially drive up the cost of the maintenance dredging. In order to avoid this, bid schedules were prepared so the interested contractors could bid on the demonstration dredging and/or the maintenance dredging. The winning contractor performed both the demonstration and maintenance dredging. Since dredging rates affect the amount of resuspended sediments in the water column and thus the release of contaminants to the water column, it was determined that the dredges should be evaluated at various production rates. Therefore, bid schedules were set up so that the contractor was paid on an hourly basis for the demonstration dredging.

Numerous other contracts were awarded to perform sample collection, to prepare samples and conduct laboratory analysis, conduct side scan sonar surveys and low level (parts per trillion) PAH and PCB analysis and conduct biological and chemical sampling and analysis. In addition, the U.S. Army Engineer Waterways Experiment Station (WES) prepared the project sampling plan, conducted field monitoring and sample collection, and is in the process of analyzing the data and preparing the project report. Also, the U.S. Bureau of Mines performed a flocculation study on the hydraulically dredged sediments.

An environmental assessment (EA) describing existing conditions, the project plan, and impacts of the project was prepared in May 1992. After coordination with numerous Federal, State, and local governmental agencies and private organizations, the EA was completed and the Finding of No Significant Impact (FONSI) was signed in June 1992. With the EA completed and contracts in place, the demonstration could proceed.

## Description of Demonstration

Demonstration dredging was initiated at Dead Man's Creek on July 27, 1992, with an open bucket. All three demonstration dredges, the open bucket, enclosed bucket, and submersible pump, were used at the Mobil Oil site from 30 July through 7 August 1992 (Figure 3). The demonstration dredging was completed on 8 August at Dead Man's Creek with the submersible pump dredge. A silt screen was installed around the mechanical dredge operations during the early portion of the demonstration at Dead Man's Creek. Periods of heavy rainfall caused river water velocities to range from 0 to 2.5 ft per second and average background total suspended solids (TSS) concentrations to range from 15 to 410 mg/L.

Objectives of the demonstration dredging included evaluating the three dredge methods to determine their effectiveness in minimizing sediment resuspension and contaminant release to the water column, evaluating the effect of dredge production rate on sediment resuspension and contaminant release, and evaluating the effectiveness of silt screens to reduce suspended sediment transport. In addition, work was undertaken to determine the long-term effect of dredging on sediment-dwelling biota, determine the leachate characteristics of dredged sediment, and determine the ability of flocculant to settle particulates out of supernatant water associated with hydraulic dredging.

WES prepared a document entitled "Buffalo River Dredging Demonstration Project Sampling and Analysis Plan" (Averett 1992) in June 1992. Following this plan, over 2,000 water column samples were collected during the 2 weeks of demonstration dredging. Samples were taken as close to the actual dredging operation as safety allowed and up to 3,000 ft upstream and downstream of the dredge site (Figure 4). The sampling program was designed to help determine sediment resuspension rate, assess sediment and contaminant transport, and evaluate water column contaminant concentrations. For example, mechanical dredge cycle times were purposely varied from roughly one and one-half to four minutes, to determine the effects of dredge production rates on water quality. This sampling proceeded as all three dredge types performed at varying operating speeds. Water column samples were analyzed for total suspended solids, total organic carbon (TOC), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), metals, ammonia, and pH. A current meter was used to measure river current velocity, while a water column profiler was used to measure water depth, temperature, conductivity, pH, percent transmission of light, and dissolved oxygen as the profiler was lowered and raised through the water column. Composite surficial sediment samples were collected in the demonstration dredging areas as soon as dredging operations were discontinued in an area. The composite samples were analyzed for metals, PAHs, TOC, pH, grain size, Atterberg limits, and moisture content to evaluate the characteristics of sediment remaining on the river bottom after dredging.

Laboratory dredging elutriate tests were performed to add to the knowledge base for prediction of contaminant releases at the point of dredging. Samples of the dredged material and river water were collected and used to perform the dredging elutriate test. This test requires mixing sediment and river water at a concentration of 10 g total solids per liter for 1 hr followed by a settling period of 1 hr and elutriate collection. The elutriates were analyzed for total and dissolved heavy metals, TOC, suspended solids, pH, and conductivity. To evaluate environmental effects that may not be explained by chemical data and to assess the significance of chemical concentrations, selected sediment plume and river stations were sampled for laboratory toxicity testing. The organism *daphnia magna* was used to assess the toxicity effects. Additionally, dredged areas were surveyed before and after completion of dredging with each dredge type to physically characterize the bottom sediment.

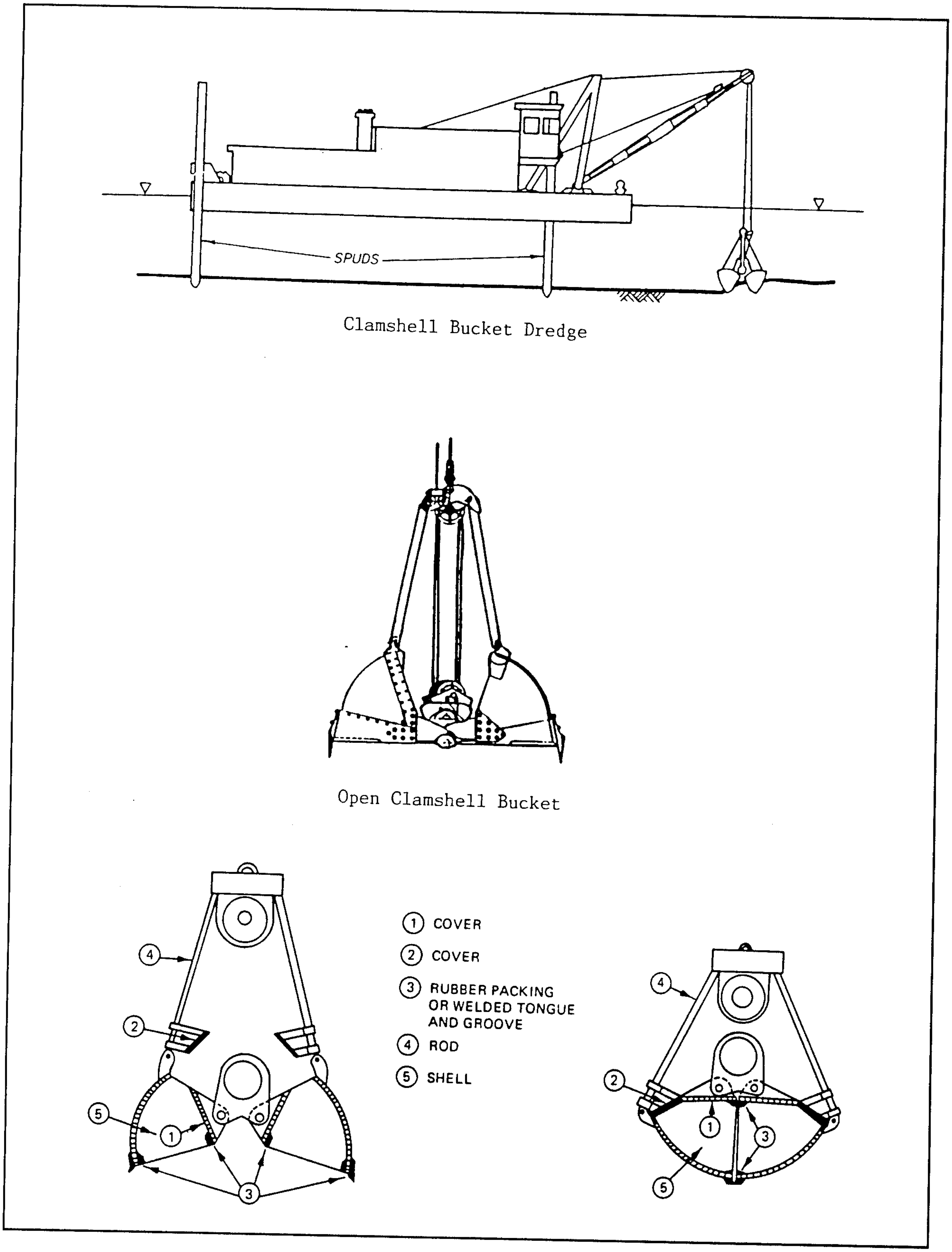


*Figure 3. Clamshell buckett dredge*

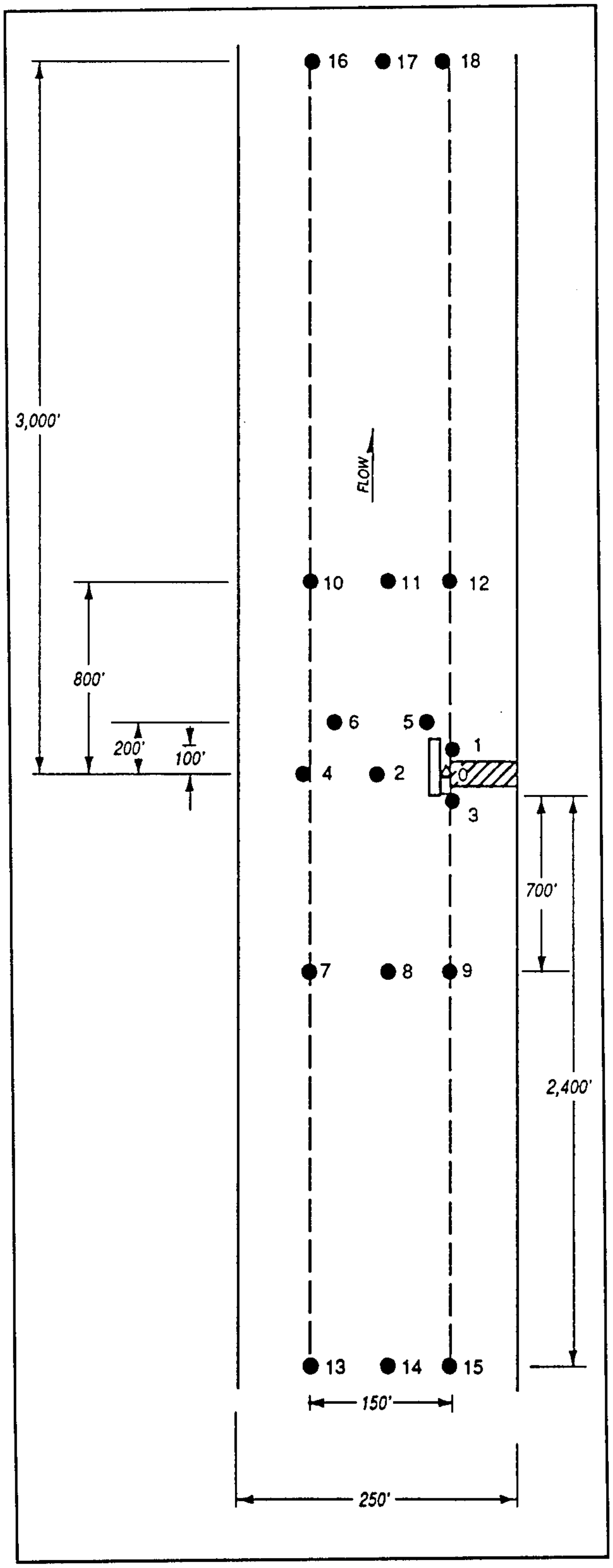


***Figure 4. Total suspended solids sample stations, Dead Man's Creek***

The above work was performed by the Corps of Engineers and its contractors, including members of universities and colleges in the Buffalo area. In another phase of this project, the U.S. Bureau of Mines tested the use of flocculants to remove particulates from supernatant water associated with hydraulic dredging (Figure 5). A slightly anionic polymer was selected for the field demonstration. A series of polymer concentrations, 0.01, 0.02, and 0.03 percent, were prepared and used. The high rate of feed pumped into the clarifier tank created turbulent conditions that allowed some of the flocculated material to overflow with the clean water.

Another portion of this study involved collecting sediment samples from the demonstration dredge area before and after dredging. Methods of studying deformities in benthic organisms have been developed to be used as a possible indicator of sediment contamination. Therefore, chironomid larvae (an aquatic insect) were removed from the Buffalo River sediment and studied for structural abnormalities at the same time metals analyses were performed on the sediments. Samples were collected and analyzed for up to several months after completion of the dredging in an attempt to determine if the removal of contaminated material had any beneficial effect on the aquatic organism.

As an additional study, a pilot-scale leachate test facility was constructed in the Buffalo District's confined disposal facility (CDF) to provide information on leachate quality in dredged material placed in the CDF during the demonstration dredging. Roughly 75 cu yd of mechanically dredged sediment was placed in a lined four 4-ft-high by 30-ft-diam steel tank. A center drain was installed, and leachate is drained through a filter fabric and clean sand layer to the outside perimeter of the tank for collection. Periodically, leachate samples are collected and analyzed for PAHs, metals, TOC, electrical conductivity, and pH to determine changes in leachate quality over an extended period of time.

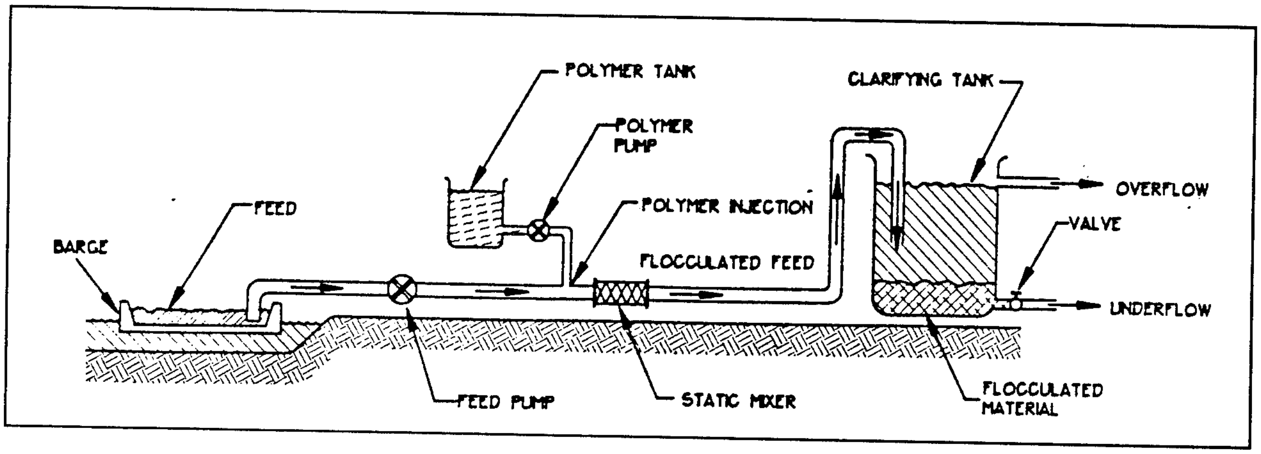


*Figure 5. Flow diagram for flocculation study*

## Summary

WES is in the process of analyzing the results of the demonstration dredging and preparing a draft report. Early results indicate that for the open clamshell bucket, total suspended solids (TSS) concentrations increased approximately 50 to 60 mg/L above background conditions 200 ft downstream of the dredge operation and that there was little or no increase in TSS within 300 to 1,100 ft downstream. For the enclosed clamshell bucket, TSS concentrations increased approximately 40 to 60 mg/L above background conditions 300 ft downstream and returned to background conditions within 1,100 ft of the dredge operations. For the submersible pump dredge, TSS concentrations increased 60 to 70 mg/L above background conditions 200 ft downstream and returned to background conditions within 1,100 ft downstream of the dredge operations. However, it should be noted that the production rate of the submersible pump was significantly less than the production rates of the open and enclosed buckets. The effect of the demonstration dredging on the chemistry of the Buffalo River has not been determined at this time. The report for the demonstration dredging project should be available from WES by approximately the middle of 1994. Detailed results will be presented in this document.

A brief document was prepared by the U.S. Bureau of Mines describing their flocculation demonstration and results. It was determined that the addition of small quantities of a slightly anionic polymer was effective in removing particulates from the supernatant water associated with hydraulic dredging (Church, Smith, and Hammer). The studies of the effect of dredging on chironomid larvae and the leachate quality in dredged material placed in the CDF are ongoing and results are not available at this time. The leachate study being conducted by WES is anticipated to be a multiyear study. Results will be made available upon the completion of these studies.

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# Pilot-Scale Demonstrations of Thermal Desorption for the Treatment of Contaminated River Sediment

*by*

*B. Thomas Kenna,[1] David Conboy,[1] Judith Leithner,[1] Daniel E. Averett,[2] and Stephen Yaksich[1]*

## Introduction

The 1987 Amendments to the Clean Water Act, Section 118(C)(3), authorized the U.S. Environmental Protection Agency's Great Lakes National Program Office (GLNPO) to conduct a 5-year study and demonstration project on the control and removal of toxic pollutants in the Great Lakes, with emphasis on the removal of toxic pollutants from bottom sediments (U.S. Environmental Protection Agency 1992). The Governments of Canada and the United States have identified 43 Areas of Concern (AOC) in the Great Lakes Basin where one or more of the objectives of the 1978 Great Lakes Water Quality Agreement and other jurisdictional standards, criteria, or guidelines are not met. GLNPO initiated the Assessment and Remediation of Contaminated Sediments (ARCS) Program to assess the nature and extent of bottom sediment contamination at selected AOCs, evaluate and demonstrate remedial options, and provide guidance on the assessment of contaminated sediment problems and the selection and implementation of remedial actions in the AOCs and other locations throughout the Great Lakes.

The legislation that created the ARCS Program specified that five of the Great Lakes AOCs should receive priority consideration in locating and conducting onsite demonstration projects. The priority AOCs included the Sheboygan River and Harbor, the Grand Calumet River and Indiana Harbor Ship Canal, the Saginaw River System and Saginaw Bay, the Buffalo River, and the Ashtabula River. The Ashtabula and Buffalo rivers were designated as priority AOCs because past industrial and municipal discharges have polluted the rivers and sediments, degrading beneficial uses of these waterways. The demonstration projects at these two sites were managed by the U.S. Army Engineer District, Buffalo, under the ARCS program.

## Objective

The objective of the pilot-scale demonstrations was to evaluate thermal desorption as a treatment technology for contaminated sediments in Great Lakes AOCs. Specific objectives of the pilot-scale demonstration included determining the following: the effectiveness of thermal desorption in removing the polycyclic aromatic hydrocarbons (PAHs) of concern in Buffalo River sediment and the polychlorinated biphenyls (PCBs) and chlorinated organic contaminants of concern in the Ashtabula River sediments; the effect of varying solids content and residence time on removal efficiencies; the contaminant partitioning within the various waste streams by doing a complete mass balance around the process; the air emissions associated with the process including analyzing for PCBs and dioxin and furan compounds; and the pretreatment, material handling, and processing requirements for the sediment. Another objective was to provide information to be used in the development of cost estimates for full-scale remediation. Additionally, for the Buffalo River demonstration project, a test of solidification/stabilization was conducted on the treated sediment.

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## Sediment Quality and Characteristics

### Ashtabula River

The Ashtabula River Remedial Action Plan states that the contaminants of greatest concern are PCBs, hexachlorobenzene, hexachlorobutadiene, mercury, zinc, chromium, and volatile organic compounds. Sediment in the vicinity of the upper turning basin of the river contains PCBs at concentrations in excess of 50 mg/kg, causing it to be regulated under the Toxic Substances Control Act (TSCA). A study conducted in 1983 estimated that there were approximately 250,000 cu yd of sediment in the Ashtabula River that would be regulated under TSCA (U.S. Army Corps of Engineers 1983). Data obtained during Ashtabula River sediment sampling conducted by Woodward Clyde consultants in 1991 showed the following maximum concentrations detected in the river: PCBs, 660 mg/kg; hexachlorobenzene, 45 mg/kg; hexachlorobutadiene, 560 mg/kg; chlorobenzene, 10 mg/kg; mercury, 11.3 mg/kg; zinc, 2,463 mg/kg; chromium, 5,470 mg/kg; arsenic, 31 mg/kg; barium, 2,152 mg/kg; lead, 282 mg/kg; and nickel, 142 mg/kg.

### Buffalo River

Samples collected at 10 sites along the Buffalo River in 1989, 1990, and 1991 showed the following contaminant levels: Chromium ranged from less than 13 mg/kg to 312 mg/kg, while concentration levels for mercury ranged from 0.0109 to 1.93 mg/kg; lead concentration ranged from 28 to 314 mg/kg, while zinc concentrations ranged from 32 to 900 mg/kg; benzo(a)pyrene concentration ranged from 54 to 2,500 µg/kg.

## Technology Description

### General Description

Thermal desorption technology involves the separation of contaminants from a solid matrix by heating the material to volatilize amenable compounds. Generally, this technology is used for removing organic contaminants since these compounds have a lower boiling point than inorganic materials. The technology, however, has shown some effectiveness in removing volatile heavy metals such as mercury.

Since the thermal desorption process is a separation, not destructive, technology, subsequent processes must be used for ultimate disposal or destruction of the volatilized material. These processes could involve off-gas incineration or off-gas condensation followed by incineration, or treatment of the condensed liquid.

The desorption process can be accomplished using various types of direct or indirect fired equipment. In many cases, indirectly fired methods are preferred, since they can operate in an oxygen-free environment and generate a much smaller volume of off-gas than traditional drying or incineration. Operating thermal systems to remediate chlorinated compounds in an oxygenated environment is undesirable because of the potential for producing products of incomplete combustion (PICs) such as dioxins and furans. Also, creating less off-gas is desirable because capital and operating costs for the system can be significantly reduced.

### Pilot Unit

The Remediation Technologies, Inc. (RETEC), Pilot Scale Thermal Desorption Unit was selected for both the Buffalo and Ashtabula demonstration project. A flow diagram for the process is shown in Figure 1, along with sampling points used to evaluate the effectiveness of the process.

For both projects, approximately 10 cu m of sediment were dredged and screened for processing. River water was then added to make the sediment pumpable and to determine the effect of varying solids content on removal efficiencies. Slurried sediment was

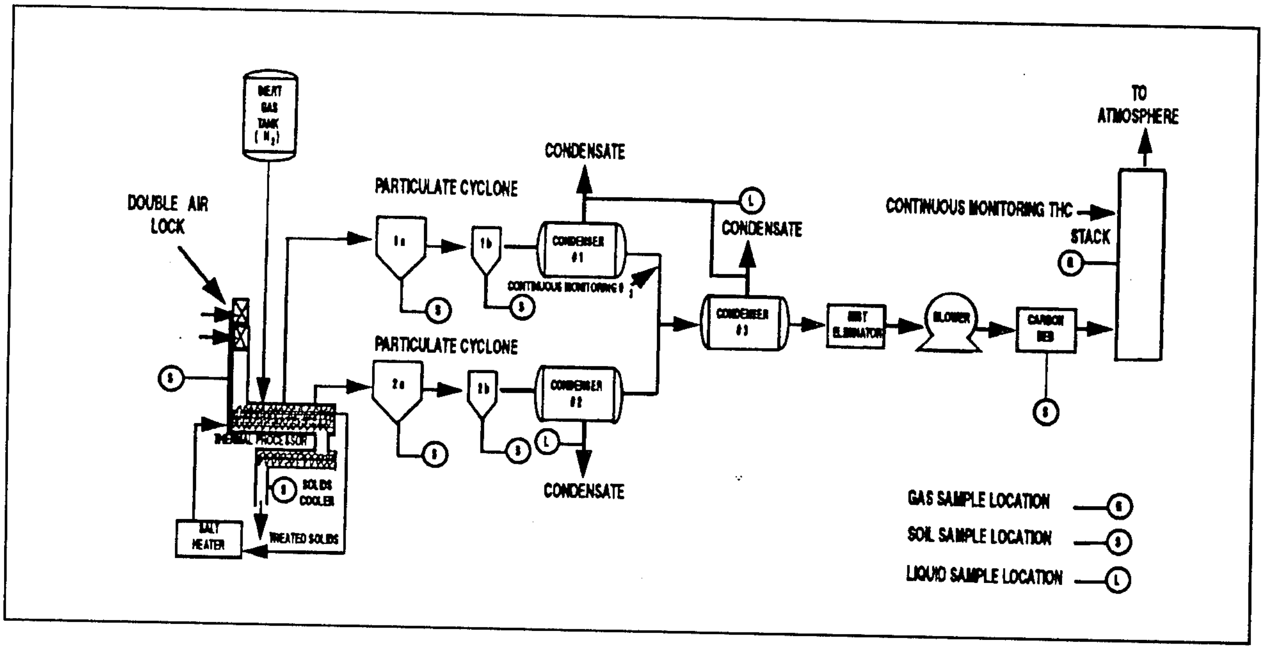


*Figure 1. Thermal desorption process flow diagram*

pumped into the treatment unit using a peristaltic pump and conveyed through the treatment unit with a Holo-Flite screw processor. The Holo-Flite processor is an indirect heat exchanger commonly used to heat, cool, and dry bulk solids and slurries. The unit consists of a jacketed trough that houses a double-screw mechanism. The rotation of the screw promotes the forward movement of the material through the processor. The speed with which the screw rotates was changed to provide different sediment residence times in the unit (RETEC 1993).

Treated solids, which should be free of volatilized compounds, were fed by gravity to a second screw device designed to cool the solids prior to discharge. This "cooling screw" was also of the Holo-Flite design and used a single auger with chilled water as the cooling media. The treated solids were discharged from the cooler through a rotary air lock into 55-gal storage drums.

Volatilized contaminants were drawn from the processor at two locations. These locations were designed to assist the separation of the organic fraction, containing the contaminants of concern, and the water. The first location was near the beginning of the processor and was designed to remove the water, which will volatilize at a much lower temperature than the chlorinated organic compounds. Accordingly, the second location was at the end of the processor where the sediment was at the highest temperature and where the higher boiling chlorinated organic compounds would volatilize.

After exiting the treatment unit, both gas streams passed through two sets of particulate cyclones to remove solid particles >10 μm that may have been entrained with the off-gases. The gas streams were then condensed separately. The first gas stream, designed to remove the water, was condensed to 38 °C. The second gas stream, designed to remove the organics, was condensed to 120 °C. This temperature was selected since it is above the boiling point of water and would provide another means of separating the water and organic fractions. Ideally, this condenser would capture or condense the organics, but allow the water to remain in a vapor phase to be condensed further downstream. Portions of the gas streams that were not condensed in the first condensers were combined and sent through a third and final condenser that was

designed to achieve an exit gas temperature of 10 °C. Two condensate streams were thus collected from the system. The first designed to be primarily an aqueous stream and the second designed to be a concentrated organic fraction. The system was driven by a variable speed rotary blower capable of developing 8.5 dry standard cu m of air per minute of flow at a vacuum of 7.62 cm of mercury (RETEC 1993).

After the air stream passed through the final condenser, it was routed through a common downflow activated carbon system (680 kg of 6 by 12 mesh vapor phase pellets) to capture noncondensable compounds and particulates prior to release to the atmosphere. Volatile organic emissions from the system were monitored in the stack on a continuous basis using a Beckman Model 400A Hydrocarbon Analyzer that continuously measured the concentration of hydrocarbons in the gas stream using a flame ionization detector (FID).

## Process Results

### Buffalo River Project

Processing was done under 12 sets of conditions with varying solids contents and residence times, each involving three to four drums of dredged material. Sediment solids content was varied from 40 to 55 percent while 30- to 90-min residence times were used. Additionally, the treated sediment was solidified/stabilized to test this technologies effectiveness in decreasing the mobility of the heavy metals remaining in the treated material. The following are the results of the project and some conclusions that can be drawn on the effectiveness of thermal desorption and the solidification/stabilization process of Buffalo River sediments.

*a.* Average contaminant concentrations in the feed sediment and percent removals are shown in Table 1.

*b.* Since copper, chromium, and lead remain with the treated sediment, the dried sediment is a candidate for remediation by solidification/stabilization technology. While solidification/stabilization with a cementitious process was not successful for chromium and copper when the material was TCLP tested, it is possible that the leachability of these metals would be reduced if the unground material was tested by exposure to normal weathering processes. Solidification/stabilization of the treated residue resulted in a 89-percent attenuation of the mobility of lead. Leachability of copper and a chromium was increased.

*c.* Removal of organic material was not strongly correlated with measured process conditions such as maximum sediment temperature, residence time, and percent solids of the feed.

*d.* Air emissions were extremely low for PAHs, dioxins, furans, and PCBs:
Low molecular weight PAHs: 1.6 to 18.0 mg/hr
High molecular weight PAHs: 0.4 to 8.6 mg/hr
Dioxins: 0.005 to 0.017 mg/hr
Furans: 0 to 0.032 mg/hr
PCBs: 1.3 to 2.4 mg/hr

### Adaptations for Ashtabula Project

As stated earlier, the Ashtabula project was conducted after the Buffalo River project, which allowed the following lessons learned from Buffalo to be applied to the Ashtabula project.

*a.* Operation at higher temperature/residence time should be used to see the effect on volatilization. Higher temperatures are especially important in Ashtabula where the contaminants of concern are higher boiling point chlorinated organic compounds.

*b.* Individual weights of each process waste stream should be obtained rather than combined weights (e.g., solids from each cyclone will be weighed and recorded separately). Taking individual weights will allow

**Table 1**
**Average Contaminant Concentrations in the Feed Sediment and Percent Removals for Buffalo River Demonstration Project**

| Parameter | Average Input Concentration | Average Removal Efficiency, % | Range of Removal Efficiencies, % |
|---|---|---|---|
| Mercury | 0.2 mg/kg | 69.2 | 9 to 100 |
| Chromium | 54.75 mg/kg | 1.4 | 0 to 9 |
| Copper | 45.8 mg/kg | 2 | 0 to 11 |
| Lead | 58.8 mg/kg | 3.1 | 0 to 8 |
| Low Molecular Weight PAHs (<4 rings) | 2.3 mg/kg | 74.2 | 45 to 90 |
| High Molecular Weight PAHs (≥4 rings) | 6.8 mg/kg | 71.4 | 42 to 96 |
| Total Organic Carbon | 1.8% | 25.7 | 5 to 35 |
| Solvent Extractable Residue | 2,009 mg/kg | 68.1 | 17 to 86 |

a more accurate mass balance calculation and determination of contaminant partitioning in the various waste streams.

*c.* The activated carbon, which the process stream passes through prior to being vented to the atmosphere, should be analyzed to determine the extent to which the contaminants of concern are partitioning to the carbon.

## Ashtabula Project

Processing was done under nine sets of conditions with varying solids contents and residence times, each involving four drums of dredged material. Sediment solids content was varied from roughly 35 to 50 percent, while 60- to 120-min residence times were used. The following are the results of the project and some conclusions that can be drawn on the effectiveness of thermal desorption process on Ashtabula River sediments.

*a.* Average contaminant concentrations in the feed sediment and percent removals are shown in Table 2.

*b.* Heavy metals other than mercury tended to remain with the sediments during thermal processing. Removal of mercury was generally a function of residence time and final sediment temperature.

*c.* Removals of chlorinated volatile materials (chlorobenzene and dichlorobenzene) exceeded 92 percent in all cases. Essentially all of the removed volatile materials were captured by the carbon adsorber. Trace amounts of volatile compounds were detected in the condensate of the process.

*d.* Removal of semivolatile materials was a function of residence time and final temperature.

*e.* Most of the mercury removed from the sediment was captured by the carbon adsorber. Trace amounts of mercury were measured in the air emissions, but were lower than regulatory limits. Average mercury air emissions were 0.014 ng per dry standard cubic meter (ng/DSCM), i.e., 0.001 percent of the mercury in the feed material. Most of the mercury trapped by the air analysis train was caught on the particulate filter.

**Table 2**
**Average Contaminant Concentrations in the Feed Sediment and Percent Removals for Ashtabula River Demonstration Project**

| Parameter | Average Input Concentration | Average Removal Efficiency, % | Range of Removal Efficiencies, % |
|---|---|---|---|
| Mercury | 1.5 mg/kg | 85 | 60 to 99.9 |
| Cadmium | 3.3 mg/kg | 16.2 | -16 to 55.8 |
| Zinc | 192.0 mg/kg | 5.2 | -7 to 12.7 |
| Lead | 51.6 mg/kg | -4.2 | -30 to 14.4 |
| Hexachlorobenzene | 0.87 mg/kg | >88 | 81 to 97 |
| Hexachlorobutadiene | 0.13 mg/kg | >99 | >99 |
| Total Organic Carbon | 2.2 % | 21 | 2 to 30 |
| Solvent Extractable Residue | 1,915 mg/kg | >66 | >49 to 76 |

*f.* When removed from the processed sediment, some of the semivolatile organic material (e.g., PCB, benzo(a) pyrene) concentrated in the condensate. Negligible amounts of semivolatile materials appeared in the carbon adsorber. Dichlorobenzene are hexachlorobutadiene concentrated in the carbon adsorber.

*g.* Air emissions for total dioxins ranged from 0.0071 to 0.0825 ng/DSCM, and air emissions for total furans ranged from 0.0041 to 0.2669 ng/DSCM. These dioxins and furans were either imported with the sediments or were generated by the process, as readings for ambient air were 0.0001 ng/DSCM for dioxins and were below detection limits for furans. Unprocessed sediments were not analyzed for dioxins and furans, so the source of these contaminants is not known for certain.

## Cost for Full-Scale Implementation

Estimated costs for full-scale implementation were calculated for both Buffalo and Ashtabula river projects. Projected costs for Buffalo ranged from $535/cu yd for 10,000 cu yd to $350/cu yd for remediation of 100,000 cu yd of sediment. For Ashtabula, the costs ranged from $440/cu yd for 10,000 cu yd to $270/cu yd for remediation of 100,000 cu yd of sediment. The primary reason the Ashtabula projected costs were lower is because this project assumed that an off-gas incinerator would be attached to the processor, reducing condensation and subsequent disposal costs. However, off-gas incineration results in higher fuel costs and potentially much higher costs associated with complying appropriate regulations.

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# Hot Spot Remedial Action, New Bedford Harbor Superfund Site

*by*
*Mark J. Otis*[1]

## Introduction

New Bedford is a port city located in southeastern Massachusetts, approximately 55 miles south of Boston (Figure 1). Sediments throughout the harbor are contaminated with polychlorinated biphenyls (PCB) and heavy metals as a result of discharges from industries that operated along the waterfront. The harbor has been the focus of intensive study since the late 1970s and was added to the U.S. Environmental Protection Agency's (EPA) Superfund National Priorities List in July 1992. Since that time, EPA has conducted investigations and studies as part of the Superfund process that resulted in an April 6, 1990, Record of Decision for the hot spot portion of the site. This paper addresses the selected remedy for the hot spot with the focus on the dredging, water treatment, and water quality monitoring components.

## Site Description

In the course of studying the site, EPA has divided it into three geographical study areas: the hot spot area, the Acushnet River Estuary, and the Lower Harbor and Upper Buzzards Bay. The hot spot is a 5-acre area located along the western bank of the Acushnet River Estuary (Figure 1), directly adjacent to an electrical capacitor manufacturing facility that was the major source of PCB discharges to the harbor. EPA defines the hot spot as those areas where the sediment PCB concentration is 4,000 parts per million (ppm) or greater. Concentrations to over 200,000 ppm have been detected in this area. Contamination at these levels is found at depths up to 4 ft, but for the most part, within the top 2 ft of sediment. In addition to PCBs, heavy metals (notably cadmium, chromium, copper, and lead) are found in the sediment. The volume of sediment to be removed from the hot spot is approximately 10,000 cu yd, and it contains approximately 45 percent of the total PCB mass in sediment from the entire site (EPA 1991a).

The remedy selected by EPA consisted of the following components:

- Dredging of the 10,000 cu yd of sediment using a small hydraulic pipeline dredge (cutterhead).
- Disposal and dewatering of the sediments with treatment of the water resulting from the dewatering process using best available control technology prior to discharge back into the harbor.
- Incineration of the sediments with disposal of the ash in the confined disposal facility (CDF) located adjacent to the harbor.
- Capping the CDF.

## Remedial Design

The Corps of Engineers performed the detailed design of the remedy with the work being carried out at both the U.S. Army Engineer Division, New England, and the U.S. Army Engineer District, Omaha. The major technical issues addressed during the design effort included the following:

- Development of dredging specifications.
- Detailed design of a lined CDF.

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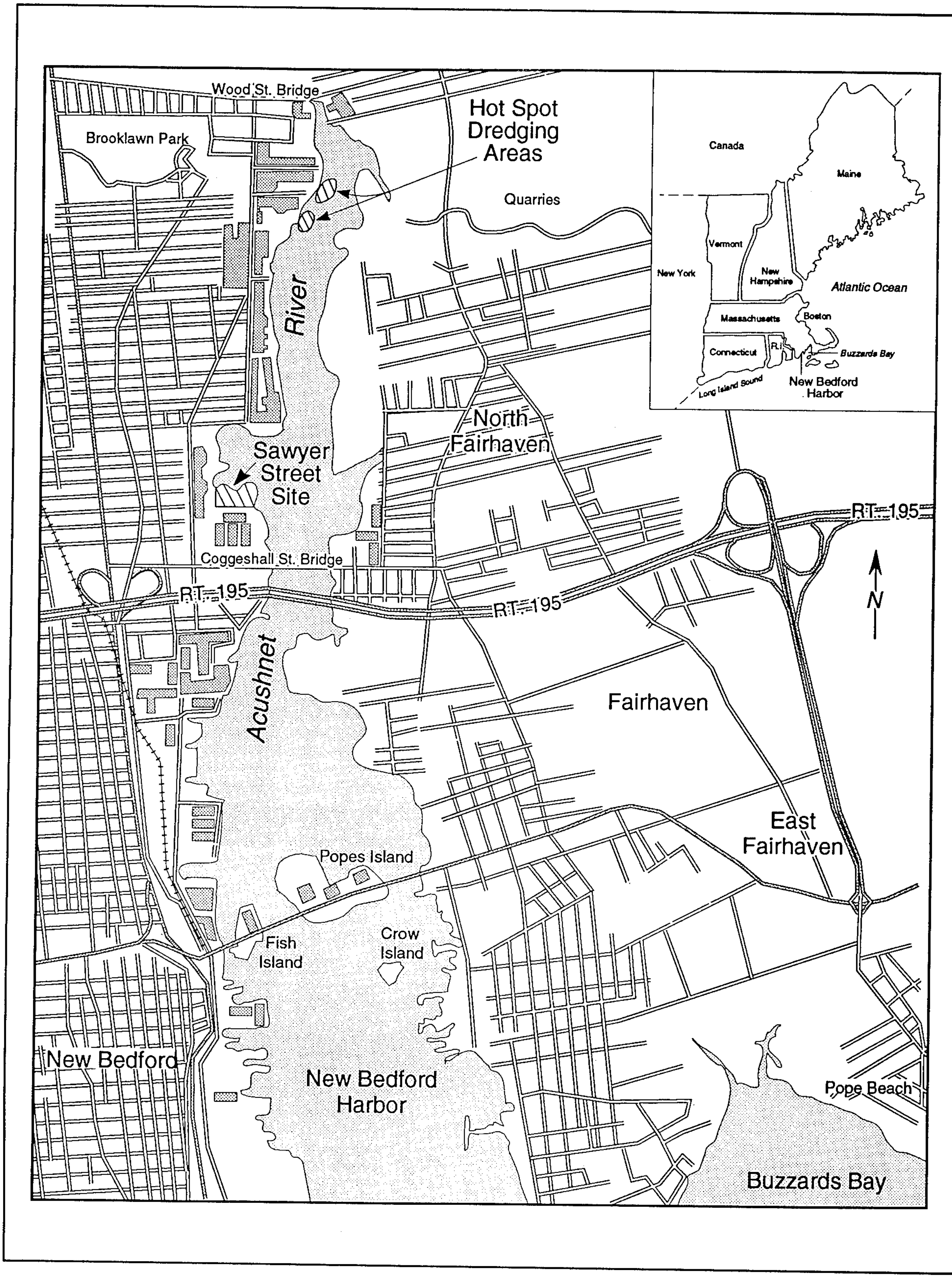


*Figure 1. New Bedford Harbor hot spot*

- Detailed design of the water treatment facility.
- Development of a performance specification for incineration of sediments.
- Development of a water quality monitoring program with decision criteria.

## Previous Corps of Engineers Studies

The Corps of Engineers had carried out several studies between 1985 and 1990 to assist EPA in evaluating dredging as a means of removing the contaminated sediments from the harbor. These studies included an Engineering Feasibility Study (EFS) and a Pilot Study of Dredging and Disposal Methods. The EFS evaluated the engineering feasibility of a number of dredging and disposal alternatives and involved investigations of the physical characteristics of the site, modeling to address the magnitude and migration potential of contaminant releases because of resuspension of sediments during dredging, and laboratory and bench-scale testing to develop data needed to predict the behavior of sediments placed in various disposal environments (Francingues, Averett, and Otis 1988). The pilot study involved the onsite evaluation of three hydraulic dredges and two disposal methods along with an extensive water quality monitoring program. The major technical objectives of this field study were to determine the dredges' ability to remove the contaminated sediment while minimizing sediment resuspension and contaminant release (U.S Army Corps of Engineers 1990). The studies resulted in the Corps of Engineers' recommendation to EPA that a cutterhead hydraulic pipeline dredge should be used to remove the contaminated sediments from the harbor.

## Dredging Plan

Site-specific dredging procedures were developed during the pilot study that resulted in the removal of the contaminated sediments while minimizing the resuspension of sediments. These operating procedures reflected the physical constraints of the harbor that include shallow water (0 to 1 ft available at low water) and limited access to the site. A cutterhead dredge utilizing these procedures was specified for use in the hot spot. The requirements that were included in the project specifications are shown below:

- Pump discharge size: not less than 8-in. diam nor more than 12-in. diam.
- Swing speed: 50 percent of dredge capability.
- Cutterhead rotation: 50 percent of dredge capability.
- Dredge pump speed: run at maximum RPM.
- Avance per swing: 2 ft (cutterhead diameter).
- Swing anchors: to be placed on shore.
- Depth of cut: sufficient to remove the top 1 ft of sediment with each pass (cutterhead location at approximately 2 ft (cutterhead diameter) below the sediment/water interface).

Shallow-water conditions at the hot spot (0 to 1 ft of water at low water, 4-ft tide range) will require use of a small dredge (Ellicott Model 370) and restrict operations to approximately a 4-hr period around high tide. We estimate that 80 days of dredging over a 120-day period will be required to remove the contaminated sediments. A silt curtain/oil boom will be used during the dredging operations as a deterrent to suspended and floating material migrating from the dredging operation. The silt curtain/oil boom will be deployed to encircle the operating dredge.

## Confined Disposal Facility

A CDF was constructed during the pilot study and used to contain the sediments removed from the harbor during that operation. This facility was constructed on the New Bedford shoreline (Figure 2), partially upland and partially below the high water line. This

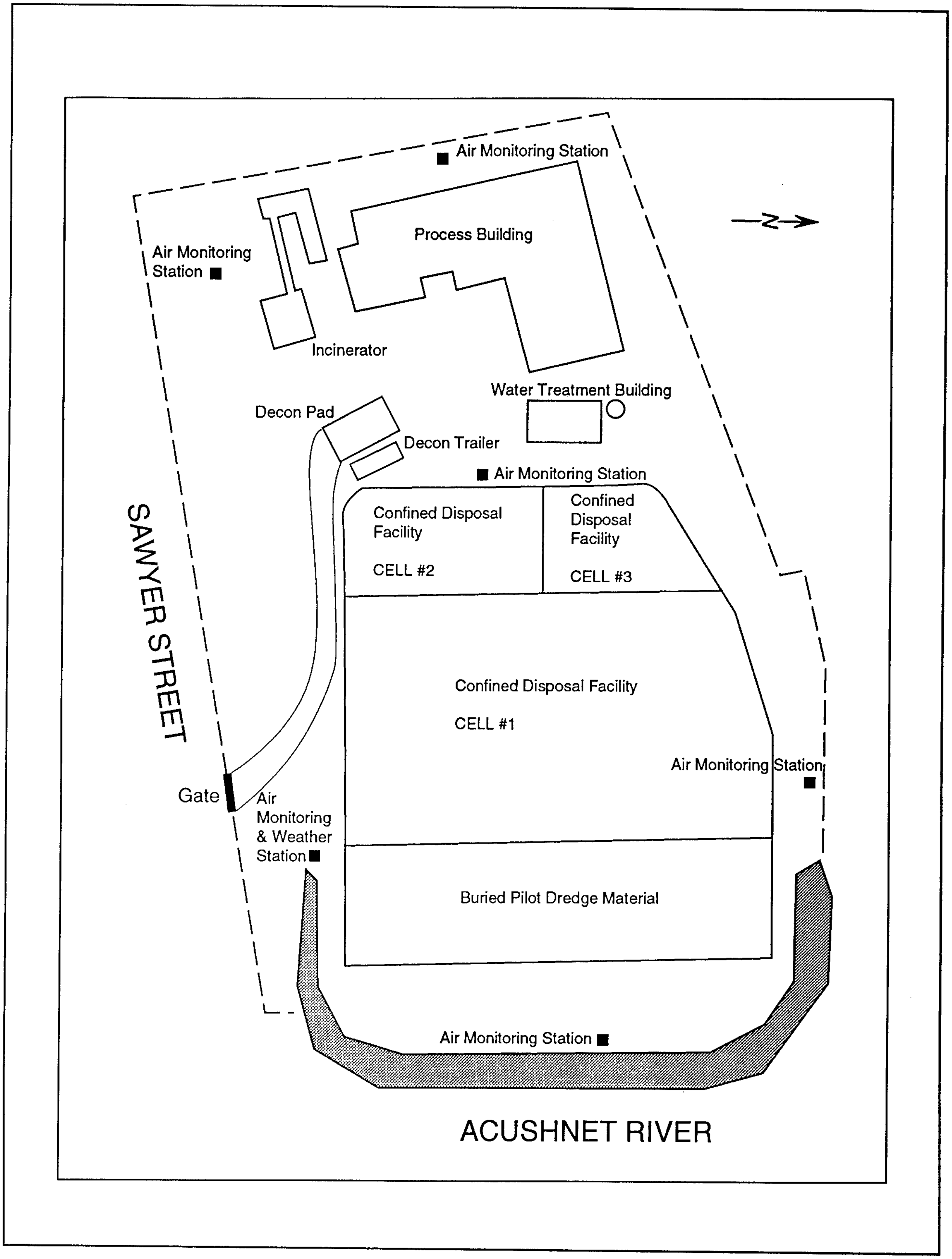


*Figure 2. Sawyer Street site*

facility will be used again during the hot spot remedial action. The dredged material is to be initially pumped into the CDF prior to being moved through mechanical dewatering and incineration. The ash resulting from the incineration process will be placed back into the CDF and capped.

Extensive modifications were made to the CDF, which included dividing the facility into three cells to facilitate the water treatment process as well as the installation of an 80 mil high-density polyethylene geomembrane liner.

## Water Treatment Facility

ERM-New England, under contract to the Omaha District, designed a 350-gal per minute water treatment process consisting of the following steps:

- Equalization tank (CDF cell 2).
- Flocculation tanks (Alum used as the flocculent).
- Secondary clarifier (CDF cell 3).
- Automatic backwash filter unit.
- Polishing filters.
- Ultraviolet hydrogen peroxide system.

They utilized information from previous studies conducted by the Corps of Engineers and their own treatability study in designing the plant to meet the following effluent requirements:

| Contaminant | Daily Maximum, µg/L | Monthly Average, µg/L |
|---|---|---|
| PCBs | 1.3 | 0.71 |
| Cd | 10.7 | 6.0 |
| Cr | 12.8 | 7.1 |
| Cu | 14.9 | 8.3 |
| Pb | 8.5 | 4.8 |

## Water Quality Monitoring

An extensive monitoring effort was carried out during the pilot study that was based on a strategy and decision-making framework developed specifically for this site. The site-specific approach was needed because Federal and State water quality standards for PCBs and metals were exceeded in New Bedford Harbor under preoperational baseline conditions. The philosophy adopted during the project was that some short-term environmental impact was worth long-term improvement in water quality. Some short-term minor increases in water chemical concentrations and biological impacts in the immediate vicinity of the dredging were considered acceptable; however, any far-field impacts were considered unacceptable (Nelson and Hansen 1991). Monitoring stations were located to reflect this philosophy with stations positioned in close proximity to the operating dredge as well as several miles away at the entrance to the harbor. Numerical decision values were established at each station for a number of physical, chemical, and biological parameters based on data collected prior to the initiation of dredging. Monitoring was carried out daily during the pilot study, and the data generated was compared with the decision values and used to manage the ongoing dredging and disposal operations. This same approach will be used during monitoring of hot spot dredging with several modifications.

The goal of the hot spot remedial action is the removal of a substantial percentage of the PCBs from the upper estuary without causing any significant additional risk to human health or the environment. The monitoring approach is to set criteria that limit net transport of PCBs associated with hot spot dredging operations to an "acceptable" level so that additional remediation in the lower harbor is not required.

Biological criteria will also be set and will serve two purposes; a reality check on the chemical data and a screen for the presence of toxicity associated with contaminants for which we are not monitoring. The biological criteria are based on bioaccumulation of PCBs in mussels and the following toxicity tests: sea urchin sperm cell test, the red alga reproductive test, and the 7-day mysid growth and survival test (EPA 1991b).

The Coggeshall Street Bridge (Figure 1) will again be the critical monitoring station. The bridge separates the highly contaminated estuary portion of the site from the less contaminated lower harbor. The bridge also restricts flow to an approximately 100-ft-wide channel, which allows for sampling of the entire channel cross section. Preoperational data has been collected and will be used to set chemical, physical, and biological criteria.

The monitoring approach based on PCB net transport was developed at EPA's Environmental Research Laboratory in Narragansett, RI. EPA Narragansett calculated that 240 kg of PCBs (above background) could be transported to the lower harbor over the entire remedial action without increasing the mean lower harbor sediment concentration by more than 1 ppm (EPA 1991b). This value will be used as the not to exceed upper limit. Monitoring will be conducted daily during dredging operations with ebb and flood tide composite samples being analyzed and used to calculate the daily PCB flux. The data generated daily will be used to calculate a cumulative total of PCB net transport that will be compared with the 240-kg upper limit throughout the operation. Adjustments to the dredging operation will be made as necessary if the rate of contaminant release appears excessive based on the planned duration of dredging and this upper limit. As a point of comparison, EPA currently estimates that up to 730 kg of PCB move to the lower harbor on an annual basis. Using information developed during the EFS and Pilot Study, the Corps of Engineers estimated that 40 kg of PCBs above background would be released to the lower harbor as a result of hot spot dredging.

## Remedial Action

Work at the site is currently underway. The CDF was modified in 1992 at a cost of $2,200,000, and a $20 million contract was awarded to Perland Environmental Technologies in August 1992 to dredge, dewater, and incinerate the hot spot sediments along with treating the water and disposing of the ash. A separate $1.1 million contract with Normandeau Associates will be used to carry out the monitoring effort. The project schedule has been disrupted by local opposition to the incineration phase of the project, but we anticipate that dredging will begin in the spring of 1994.

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# Dioxin-Contaminated Sediments, a Case Study

*by*
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## Introduction

Polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDF) describe a group of compounds collectively known as dioxin. These compounds are structurally related and are formed as a result of photochemical and thermal reactions as well as high temperature chlorination reactions. The term dioxin usually refers to the most toxic and extensively studied congener, 2,3,7,8-tetrachlorodibenzo-para-dioxin (2,3,7,8-TCDD) (Gibson and Reilly 1992).

In order to assign a measure of toxicity to other PCDD and PCDF congeners, International Toxicity Equivalency Factors (I-TEF) were assigned to each congener based on its structural similarity to 2,3,7,8-TCDD in 1988. I-TEF were updated in 1989 and are used to determine impacts on the aquatic environment (U.S. Army Engineer District, Seattle).

## Background

In 1988, elevated levels of dioxin were identified in fish collected from the Sampit River by the South Carolina Department of Health and Environmental Control (SCDHEC). Dioxin toxic equivalents (TEQ) using 1988 International Toxicity Equivalency Factors (I-TEF/88) ranged from 0.0283 parts per trillion (ppt) at the mouth of the Great Pee Dee River to 3.5834 ppt in the inner harbor area (Figure 1). This prompted additional sampling of fish, shellfish, sediments, and crabs in 1989. The highest TEQ ranged from 27.56 ppt to 50.79 ppt and caused SCDHEC to issue a health advisory warning to the public not to eat fish or shellfish from the Sampit River.[2]

The U.S. Army Engineer District, Charleston, dredges approximately 1.6 million cubic yards of sediment material annually from the navigation channel in Winyah Bay and the Sampit River. Material from the dredging operation is placed in the Georgetown Ocean Dredged Material Disposal Site, in three confined upland disposal areas and in one open-water (marsh building) site (Figure 1). The presence of dioxin raised concerns among Resource Agencies about increasing the bioavailability of dioxin through dredging and the redistribution of dioxin-laden sediments.

The concerns expressed by the Resources Agencies prompted an extensive sampling effort by the Charleston District in 1992. This effort involved preliminary sediment testing followed by additional analysis, including physical, chemical, and biological testing of tissues and sediments of the proposed dredged material as described in U.S. Environmental Protection Agency/U.S. Army Corps of Engineers (USEPA/USACE) 1991.

## Materials and Methods

### January 1992 - Sediment Collection

Preliminary sediment testing for dioxin and other parameters was conducted in January 1992 from five sites located in the Inner Harbor area of Winyah Bay (USACE 1992). Samples from locations 1, 2, and 3 were collected from the navigation channel (Figure 1). Samples from location 4 were collected from

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1 U.S. Army Engineer District, Charleston; Charleston, SC.
2 South Carolina Department of Health and Environmental Control, correspondence dated May 1, 1990.

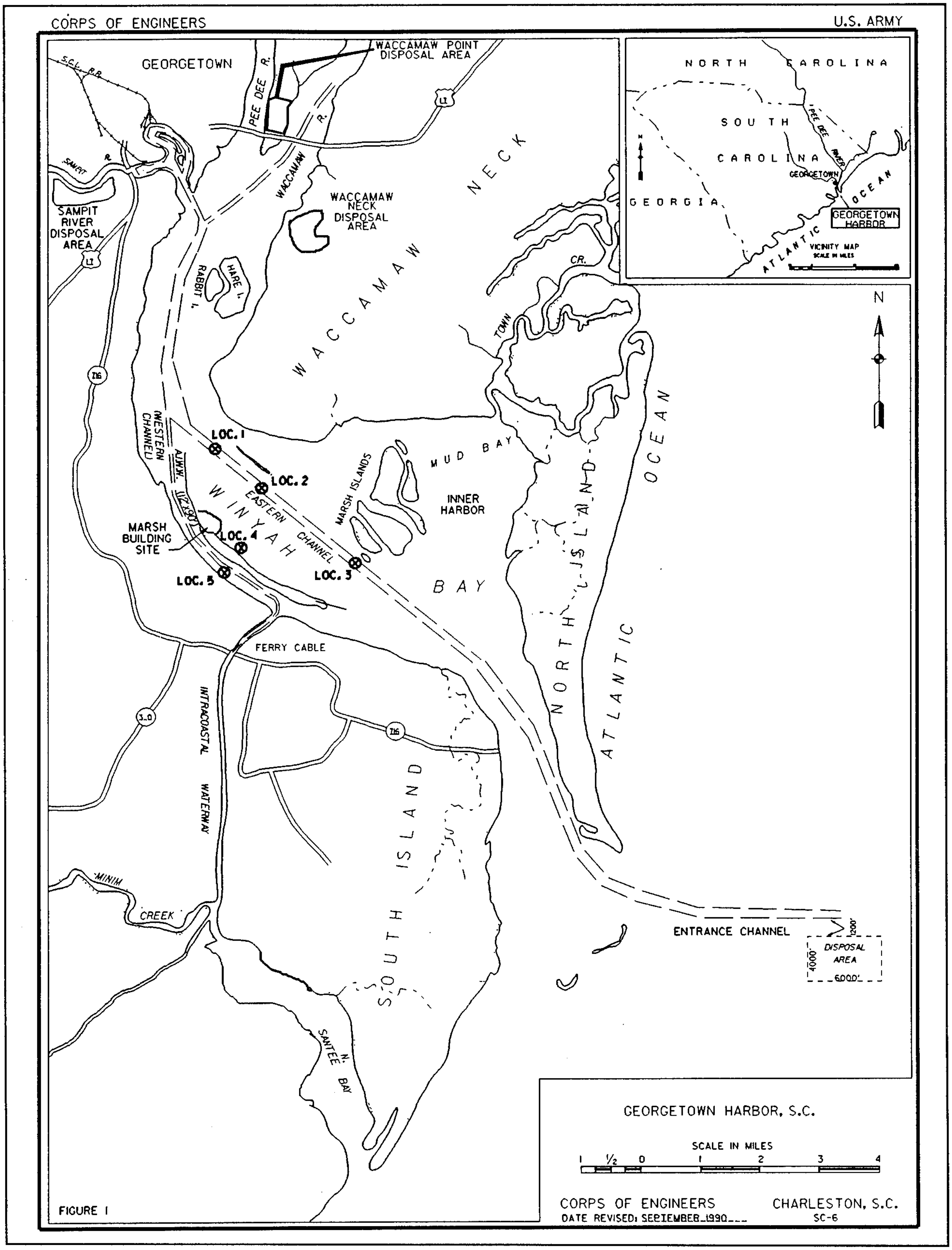


*Figure 1. Locations 1, 2, 3, 4, and 5, Inner Harbor area of Winyah Bay*

the eastern channel side of the marsh building site downstream of the silt screen within 5 m of the screen. Samples from location 5 were collected from the western channel on the southwest side of the island adjacent to the marsh building site.

A petite PONAR stainless steel, grab sampler was used to collect a minimum of three separate replicate samples per location. The replicates were composited into a homogenous mixture prior to placing the material in laboratory glass containers for analysis.

## Sediment Chemistry

The following analyses were conducted on sediments from each sampling location:

| | |
|---|---|
| Polynuclear Aromatic Hydrocarbons (PAH)<br>Polychlorinated biphenyls (PCB)/Pesticides<br>Phthalate Esters | Phenols<br>Metals<br>Dioxins |

## June 1992 - Sediment Collection

Additional testing was conducted in June 1992 (Figure 2), (U.S. Army Corps of Engineers 1993). Sediment samples were collected from three sites located in the Entrance Channel of Winyah Bay (EC-1, EC-2, and EC-3) using a sand dredge to a depth of 4 cm. Three sites located in the Inner Harbor (IH-1, IH-2, and IH-3) and four sites at the mouth of the Sampit River (SR-1, SR-2, SR-3, and SR-4) were sampled using a van Veen grab sampler to a depth of 8 to 15 cm. Reference sediment for the Entrance Channel material was collected east of the Georgetown Ocean Dredged Material Disposal Site (EC-Ref. Comp.) Sediment from two reference stations was collected for the Inner Harbor: IHR-1 was located in Clam Bank Creek in North Inlet, a National Estuary northeast of Winyah Bay. IHR-2 was located south of Hare Island in the neck of Winyah Bay. All reference sediments were collected using the van Veen or sand dredge. Samples were shipped in epoxy-coated, 5-gal buckets via refrigerated truck at 4 °C to a laboratory for analysis. Control sediments were supplied with the control organisms by private contractor and by the laboratory.

Because of the shoaling location and the length of the shoal in the Inner Harbor area, stations IH-2 and IH-3 were composited for some of the biological and chemical testing.

## Sediment Chemistry

The following physical and chemical tests were conducted on sediments from each sampling location and reference station:

| Chemical Tests | Physical Tests |
|---|---|
| Ammonia[1]<br>Sulfides[1]<br>PAH<br>PCB/Pesticides<br>Phthalate Esters<br>Phenols<br>Methylene Chloride<br>Dioxins<br>Metals[3]<br>Butyltins[2] | Grain size<br>Specific gravity<br>Atterburg limits<br>Total solids<br>Total organic carbon[2] |

[1] Tests were only conducted on the Entrance Channel stations.
[2] Tests were conducted on IH-2 and IH-3 individually and also on the composite of both stations.
[3] Test was not conducted on the Inner Harbor stations or IH-reference sites because analysis of those sediments 6 months earlier indicated that metals were not present at concentrations exceeding USEPA Water Criteria for Marine Waters.

## Test Organisms

All test organisms used in evaluating the sediment were supplied either by commercial suppliers or collected by laboratory personnel. To determine water column toxicity, 3-day suspended particulate phase (SPP) tests were conducted using the sea urchin larvae *Lytechinus pictus*. Four-day SPP tests were conducted using the crustacean *Mysidopsis bahia* and the silverside minnow *Menidia beryllina*.

Three solid phase (SP) acute toxicity tests were conducted for 10 days using the amphipods *Ampelisca abdita* and *Rhepoxinius abronius*. The third 10-day test was conducted with the polychaete *Nereis virens*. Two

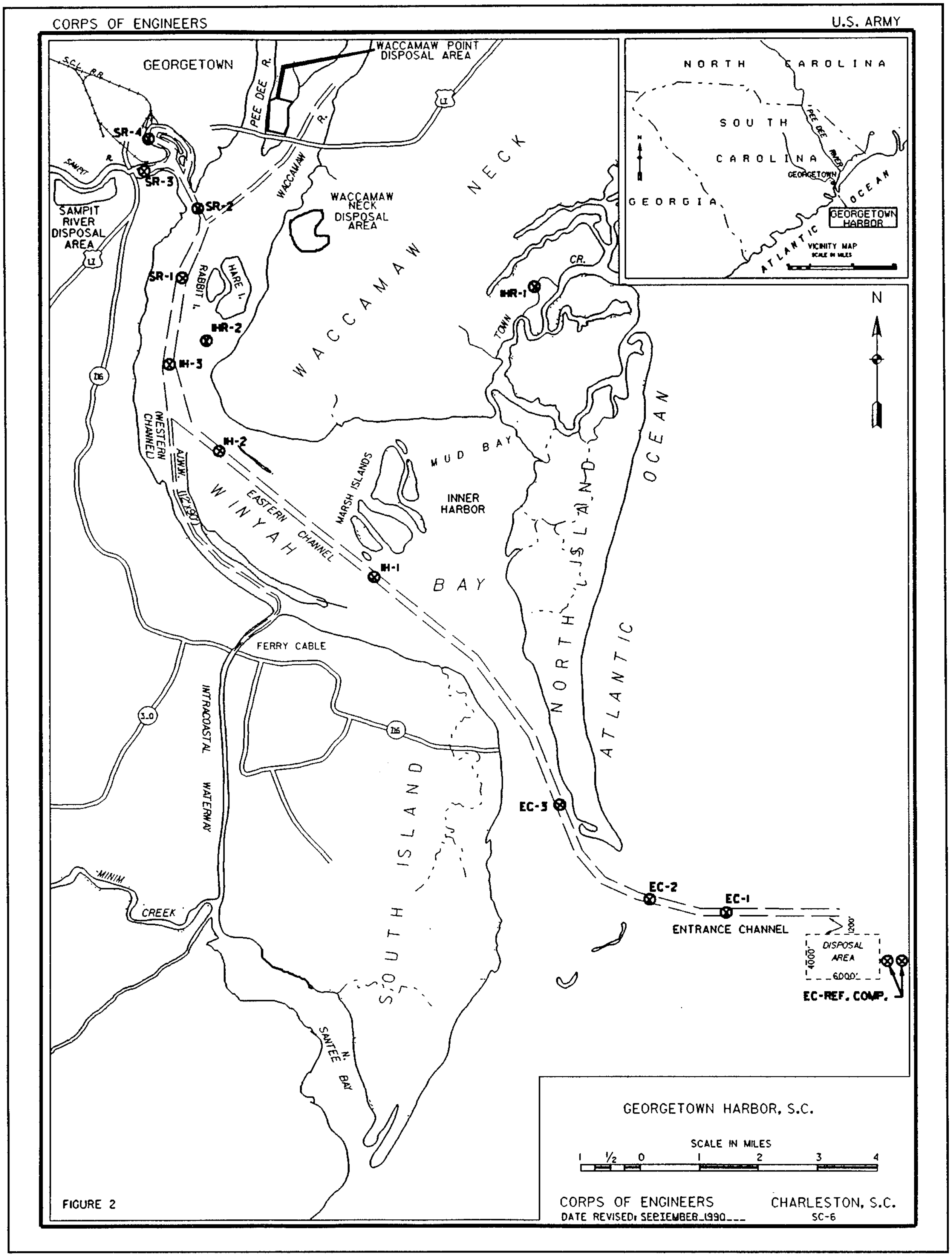


*Figure 2. Sediment sample collection locations*

bioaccumulation tests were conducted for 28 days using the bent-nose clam *Macoma nasuta* and the polychaete *Nereis virens*.

Stations IH-2 and IH-3 were composited for the 28-day SP tests. SP tests were not conducted on the Sampit River stations since this material is placed in upland disposal areas during dredging operations.

### Tissue Chemistry

Tissues associated with the 28-day bioaccumulation tests were analyzed for PAH, organotins, and dioxins based on the results of the sediment chemistry.

## Results and Discussion

For purposes of this paper, discussion will be limited to dioxin analysis. Comprehensive data are available upon request from the Charleston District.

### January 1992 - Sediment Chemistry

The sediment analysis indicated that 2,3,7,8-TCDD was present at Locations 1 and 4 with concentrations of 1.7 and 3.4 ppt, respectively. I-TEF/89 values are listed in Table 1.

**Table 1**
**Toxicity Equivalency Factors, Inner Shoal and Marsh Building Site, January 25, 1992**

| Location | I-TEF/89, ppt |
|---|---|
| #1 | 16.21 |
| #2 | 4.11 |
| #3 | 4.87 |
| #4 | 17.32 |
| #5 | 10.06 |

### June 1992 - Sediment Chemistry

The sediment analysis identified 2,3,7,8 TCDD in only two of the sampling locations, IHR-2 at 0.29 ppt and SR-1 at 1.69 ppt. Various other congeners were identified in the sediments with the highest levels being associated with OCDD. Table 2 lists the toxicity equivalency factors for the June 1992 sampling. A summary of dioxins and furans in the sediment can be found in Table 3.

**Table 2**
**Toxicity Equivalency Factors, Winyah Bay/Sampit River, June 1992**

| Location | I-TEF/89, ppt |
|---|---|
| EC-1 | 0.131 |
| EC-2 | 0.063 |
| EC-3 | 0.051 |
| EC-Ref. Comp | 0.048 |
| IH-1 | 0.478 |
| IH-2 | 1.214 |
| IH-3 | 1.231 |
| IH-Ref. 1 | 1.201 |
| IH-Ref. 2 | 0.831 |
| SR-1 | 4.987 |
| SR-2 | 2.118 |
| SR-3 | 0.920 |
| SR-4 | 1.719 |

### Bioassay Testing

The 10-day solid-phase tests indicated that there was not a significant difference between survival of the test organisms in the test sediments when statistically compared with the reference sediments.

The suspended-particulate-phase static tests were completed with no evidence of acute toxicity to the organisms.

Tissues of *M. nasuta* and *N. virens* were analyzed for dioxins and furans. The vast majority of the congeners were not significantly elevated when compared with the reference sites. The one exception was the tissues of *M. nasuta* following exposure to sediments from composite IH-2/IH-3. Significant elevations of OCDD were identified when compared with both references. A similar significant elevation did not occur in the tissues of *N. virens* following exposure to sediments from composite IH-2/IH-3. Results of the tissue analyses are summarized in Table 4.

## Table 3
## Summary of Dioxins and Furans in Sediments, Winyah Bay, June 1992

**Dioxins, Concentration, ppt**

| Sampling Sites | 2378-TCDD | 12378-PeCDD | 123478-HxCDD | 123678-HxCDD | 123789-HpCDD | 1234678-HpCDD | OCDD |
|---|---|---|---|---|---|---|---|
| EC-1 | 0.3 U | 0.1 U | 0.2 U | 0.09 | 0.4 U | 2.19 | 46.37 |
| EC-2 | 0.4 U | 0.1 U | 0.2 U | 0.1 U | 0.4 U | 1.03 | 20.63 |
| EC-3 | 0.4 U | 0.3 U | 0.3 U | 0.3 U | 0.5 U | 1.29 | 31.88 |
| EC-RefComp | 0.3 U | 0.2 U | 0.2 U | 0.2 U | 0.4 U | 0.52 | 10.44 |
| IH-1 | 0.4 U | 0.3 U | 0.20 | 0.27 | 0.96 | 10.73 | 208.90 |
| IH-2 | 1.1 U | 0.7 U | 0.31 | 0.74 | 3.6 U | 25.30 | 796.51 |
| IH-3 | 0.6 U | 0.4 U | 0.31 | 0.56 | 1.36 | 25.47 | 632.11 |
| IHR-1 | 0.3 U | 0.28 | 0.59 | 0.87 | 2.17 | 25.34 | 359.81 |
| IHR-2 | 0.29 | 0.4 U | 0.4 U | 0.36 | 1.7 U | 9.37 | 252.96 |
| SR-1 | 1.69 | 2.2 U | 2.6 U | 1.10 | 2.87 | 53.11 | 1,653.64 |
| SR-2 | 1.0 U | 0.32 | 0.44 | 0.91 | 2.21 | 38.88 | 1,027.00 |
| SR-3 | 0.6 U | 0.22 | 0.28 | 0.40 | 1.27 | 17.54 | 453.89 |
| SR-4 | 1.1 U | 0.9 U | 1.2 U | 1.32 | 4.9 U | 37.74 | 1,033.36 |

**Furans, Concentration, ppt**

| Sampling Sites | 2378- TCDF | 12378-PeCDF | 23478-PeCDF | 123478-HxCDF | 123678-HxCDF | 123789-HxCDF | 234678-HxCDF | 123478-HpCDF | 1234789-HpCDF | OCDF |
|---|---|---|---|---|---|---|---|---|---|---|
| EC-1 | 0.3 U | 0.2 U | 0.2 U | 0.2 U | 0.1 U | 0.32 | 0.1 U | 0.21 | 0.2 U | 0.25 |
| EC-2 | 0.2 U | 0.1 U | 0.1 U | 0.1 U | 0.1 U | 0.32 | 0.1 U | 0.5 U | 0.2 U | 0.17 |
| EC-3 | 0.05 | 0.2 U | 0.2 U | 0.2 U | 0.2 U | 0.90 U | 0.2 U | 0.6 U | 0.4 U | 0.76 |
| EC-RefComp | 0.3 U | 0.3 U | 0.3 U | 0.1 U | 0.1 U | 0.32 | 0.2 U | 0.6 U | 0.2 U | 0.50 U |
| IH-1 | 0.18 | 0.2 U | 0.2 U | 0.1 U | 0.1 U | 0.80 U | 0.1 U | 0.8 U | 0.1 U | 0.60 |
| IH-2 | 1.7 U | 0.5 U | 0.5 U | 0.4 U | 0.4 U | 0.43 | 0.2 U | 1.45 | 0.4 U | 2.54 |
| IH-3 | 0.67 | 0.3 U | 0.2 U | 1.6 U | 0.08 | 0.42 | 0.1 U | 3.2 U | 0.3 U | 2.87 |
| IHR-1 | 0.26 | 0.2 U | 0.2 U | 0.3 U | 0.3 U | 0.37 | 0.1 U | 0.92 | 1.2 U | 1.18 |
| IHR-2 | 0.56 | 0.4 U | 0.13 | 0.14 | 0.3 U | 0.31 | 0.2 U | 1.7 U | 0.4 U | 0.93 |
| SR-1 | 6.98 | 3.0 U | 2.2 U | 5.4 U | 1.4 U | 1.30 U | 0.9 U | 7.5 U | 1.8 U | 7.45 |
| SR-2 | 1.22 | 0.6 U | 0.4 U | 0.27 | 0.4 U | 0.41 | 0.2 U | 6.0 U | 0.4 U | 5.06 |
| SR-3 | 0.68 | 0.4 U | 0.3 U | 0.3 U | 0.3 U | 0.38 | 0.1 U | 2.2 U | 0.2 U | 1.86 |
| SR-4 | 1.71 | 1.1 U | 1.4 U | 0.9 U | 0.8 U | 1.00 U | 0.4 U | 7.0 U | 0.9 U | 5.43 |

Note: U-values indicate that the congener was not detected at the associated numerical value.

**Table 4**
**Dioxin and Furan Analysis in Tissues of *M. nasuta* and *N. virens***

| | *M. nasuta*, Concentration, ppt | | | *N. virens*, Concentrations, ppt | | |
|---|---|---|---|---|---|---|
| **Congener** | **IH-2/IH-3** | **IHR-1** | **IHR-2** | **IH-2/IH-3** | **IHR-1** | **IHR-2** |
| 2,3,7,8-TCDD | 5.32 U | 4.14 U | 6.78 U | 5.04 U | 2.26 U | 2.49 U |
| 1,2,3,7,8-PeCDD | 3.06 U | 4.10 U | 4.42 U | 6.68 U | 1.77 U | 1.61 U |
| 1,2,3,4,7,8-HxCDD | 1.96 U | 4.46 U | 4.18 | 5.84 U | 2.56 U | 1.31 U |
| 1,2,3,6,7,8-HxCDD | 4.76 | 4.83 U | 3.88 | 3.38 U | 2.63 U | 1.15 U |
| 1,2,3,7,8,9-HxCDD | 3.94 | 6.30 U | 5.44 | 4.80 U | 3.65 U | 1.66 U |
| 1,2,3,4,6,7,8-HpCDD | 19.92 | 16.53 | 16.06 | 15.52 | 10.61 | 6.22 |
| OCDD | 407.02 S | 167.64 | 305.28 | 197.92 | 74.98 | 79.76 |
| 2,3,7,8-TCDF | 4.06 | 2.97 | 5.72 | 4.68 | 2.69 | 2.75 |
| 1,2,3,7,8-PeCDF | 2.36 | 4.83 U | 3.82 U | 3.98 U | 1.40 U | 1.23 U |
| 2,3,4,7,8-PeCDF | 1.24 U | 3.90 U | 3.62 U | 4.10 U | 1.45 U | 1.61 U |
| 1,2,3,4,7,8-HxCDF | 1.46 U | 4.03 U | 4.02 U | 6.12 U | 2.40 U | 1.43 U |
| 1,2,3,6,7,8-HxCDF | 3.88 U | 4.26 U | 3.50 U | 6.12 U | 1.96 U | 1.39 U |
| 1,2,3,7,8,9-HxCDF | 3.60 | 5.44 | 5.28 | 9.90 U | 4.73 | 3.61 U |
| 2,3,4,6,7,8-HxCDF | 1.44 U | 3.49 U | 3.42 U | 9.48 U | 4.00 U | 1.39 U |
| 1,2,3,4,6,7,8-HpCDF | 14.04 U | 10.73 U | 16.16 U | 17.60 | 9.26 U | 7.41 U |
| 1,2,3,4,7,8,9-HpCDF | 1.96 U | 6.06 U | 5.50 U | 8.30 U | 2.98 U | 1.50 U |
| OCDF | 7.10 | 12.76 | 9.44 | 35.84 U | 9.17 | 8.25 |

Note: U-values indicate that the congener was not detected at the associated numerical value. S-value indicates that the congener is significantly elevated relative to references IHR-1 and IHR-2.

## Conclusions

This evaluation of addressing the potential impacts of dredged material on bio-organisms was conducted using the tiered approach described in USACE/USEPA (1991), hereinafter called the 1991 Testing Manual. The following discussion summarizes the findings of this evaluation.

### Entrance Channel

Various dioxin and furan congeners were identified in the sediments of the entrance channel and the reference site. All concentrations were less than 1 ppt with the exception of 1,2,3,4,6,7,8-HpCDD and OCDD. TEQs ranged from 0.048 ppt at the reference site to 0.131 ppt at EC-1. Interestingly, the sediment composition was 97- to 100-percent sand. These sediments exhibited no acute toxicity in the water column or benthic bioassays. In addition, the results indicated that the sediments did not contain significant contaminant bioavailability. Based on the Tier III evaluation, these sediments met the Limiting Permissible Concentration (LPC) criteria for water column and benthic impact. Based on the above findings, bioaccumlation testing was not conducted.

### Inner Harbor

Similar to the entrance channel, various dioxin and furan congeners were identified in the sediments of the navigation channel and in both reference sites. 2,3,7,8-TCDD was identified in IHR-2, but at a low concentration of 0.29 ppt. This followed the expected pattern because IH-1 was located closer to the entrance channel and was predominately sand (98 percent), whereas IH-3, located in the neck of the bay, was predominately silt (65 percent) and clay (30 percent). Based on the sediment chemistry results, bioaccumulation testing was initiated. The *1991 Testing Manual* approach requires that a statistical comparison be conducted between the contaminant levels in the test sediments and the contaminant levels of the reference site(s). In this case, a composite of IH-2 and IH-3 sediments was utilized to conduct the bioaccumulation tests, and the statistical comparison was conducted between the IH-2/IH-3 composite and both reference sites. The comparison showed no significant elevations of dioxin in the composite compared with the references with the exception of OCDD. Additional testing for dioxin will be conducted in fiscal year 1994.

### Sampit River

Grain-size analysis of the SR-sites showed a sediment composition of predominately silts and clays. Dioxin/furan concentrations increased in the sediments of the Sampit River.

In addition, 2,3,7,8-TCDD was identified at one station (SR-1) at a concentration of 1.69 ppt. Bioassay testing was not conducted with these sediments since the material is placed in upland disposal areas. However, effluent monitoring was conducted during dredging operations, with particular emphasis placed on analysis for total suspended solids (TSS) and dioxin. Results of the effluent monitoring showed that more than 97 percent of TSS are retained in the upland disposal areas.

### Summary

Test results have shown that dioxin congeners occur in minute quantities throughout the Georgetown Harbor, Winyah Bay area, in adjoining North Inlet, and in the nearshore area. Bioassay testing of navigation channel sediments and reference sites in these areas showed no significant elevation of dioxin between channel sediment samples and reference sediment samples with the exception of the OCDD congener.

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# A Summary of the Distribution and Effects of Polychlorinated Biphenyl (PCB) Contamination in Aquatic Biota in Twelve Mile Creek and Lake Hartwell, South Carolina

*by*
*C. Michael Alexander*[1]

## Introduction

The U.S. Army Engineer District, Savannah, conducted biological investigations for the Remedial Investigation/Feasibility Study (RI/FS) at the Sangamo Weston, Inc./Twelve Mile Creek/Lake Hartwell PCB Contamination Superfund Site Operable Unit Two (OU Two). These investigations were completed in concert with nonbiological investigations conducted by Bechtel Environmental, Inc. (Bechtel). These investigations were completed under the direction of the U.S. Environmental Protection Agency (USEPA), Region IV.

The goals of the biological investigations were to characterize polychlorinated biphenyl (PCB) contamination in the aquatic biota in Twelve Mile Creek and Lake Hartwell and to provide information required for assessment of effects of PCB contamination on the aquatic environment.

Initial studies in the Twelve Mile Creek watershed were conducted during Spring 1992 to (a) determine the concentration of PCBs in one primary sport fish species and one bottom-feeding species, (b) assess the condition of the fish community, (c) assess the condition of the macroinvertebrate community, (d) assess health of redbreast sunfish, (e) assess composition and fate of fish harvest, and (f) measure ongoing PCB contamination.

Studies in Lake Hartwell were conducted during Spring 1991, 1992, and 1993 to (a) determine the concentration of PCBs in primary sport and forage fish species, (b) assess health of largemouth bass, (c) determine PCB concentrations in seston and macroinvertebrates, and (d) assess composition and fate of fish harvest.

## Sampling Station Description

Twelve Mile Creek is located in Pickens County in the northwest corner of South Carolina. PCBs were discharged into Town Creek, a tributary to Twelve Mile Creek, about 12 miles upstream from Lake Hartwell. Twelve stations were established in the Twelve Mile Creek watershed and three uncontaminated tributaries. Twelve Mile Creek sites are shown in Figure 1.

Located in the northwest corner of South Carolina, Lake Hartwell was built between 1955 and 1963 by the Savannah District by damming the Tugaloo, Seneca, and upper Savannah rivers. At normal full pool elevation (660 ft above mean sea level), Lake Hartwell covers approximately 56,000 acres with a shoreline length of 962 miles. Lake Hartwell borders Anderson, Pickens, and Oconee counties in South Carolina and Stevens and Hart counties in Georgia. Six stations were selected for study in Lake Hartwell (Figure 2.)

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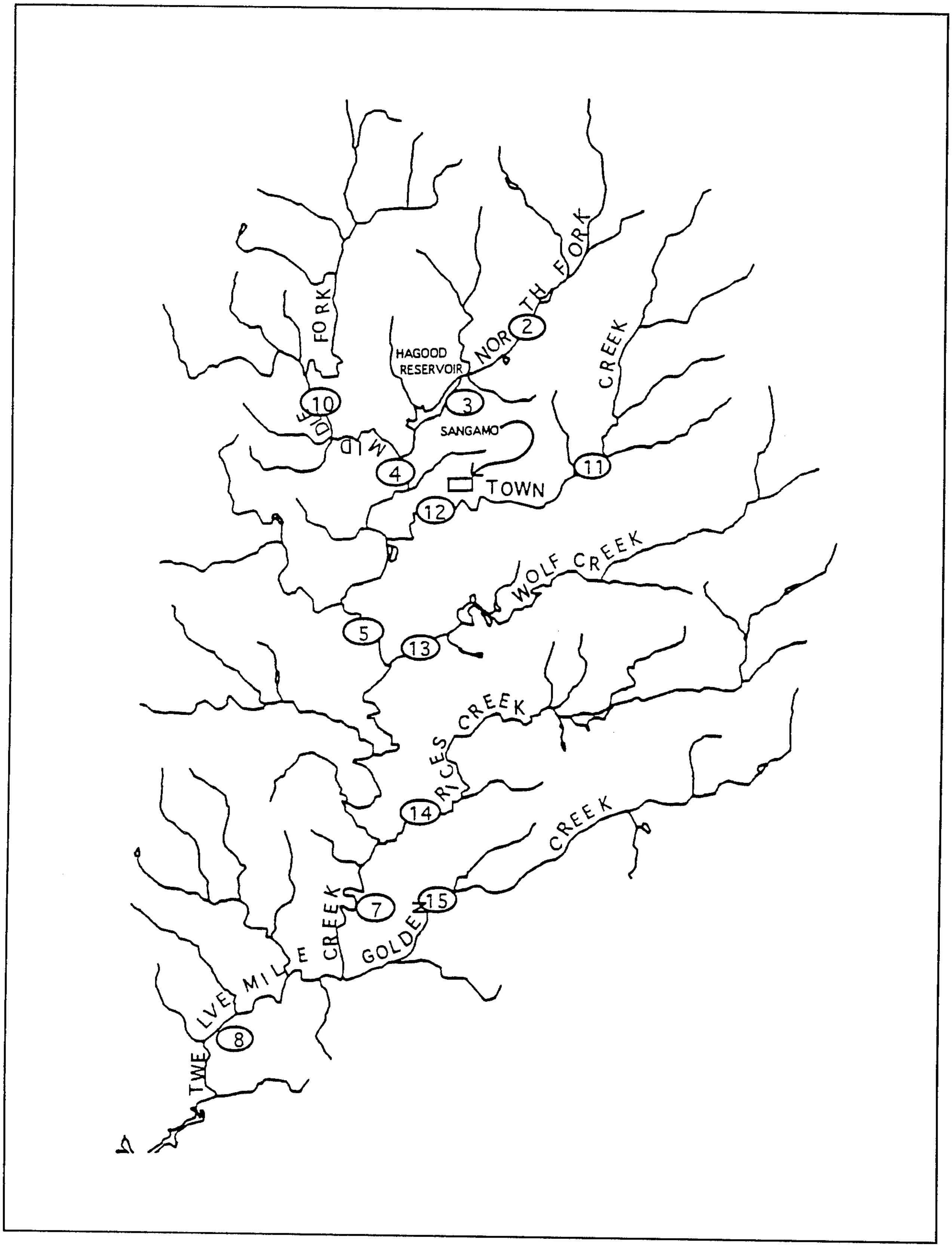


*Figure 1. Twelve Mile Creek drainage sampling stations*

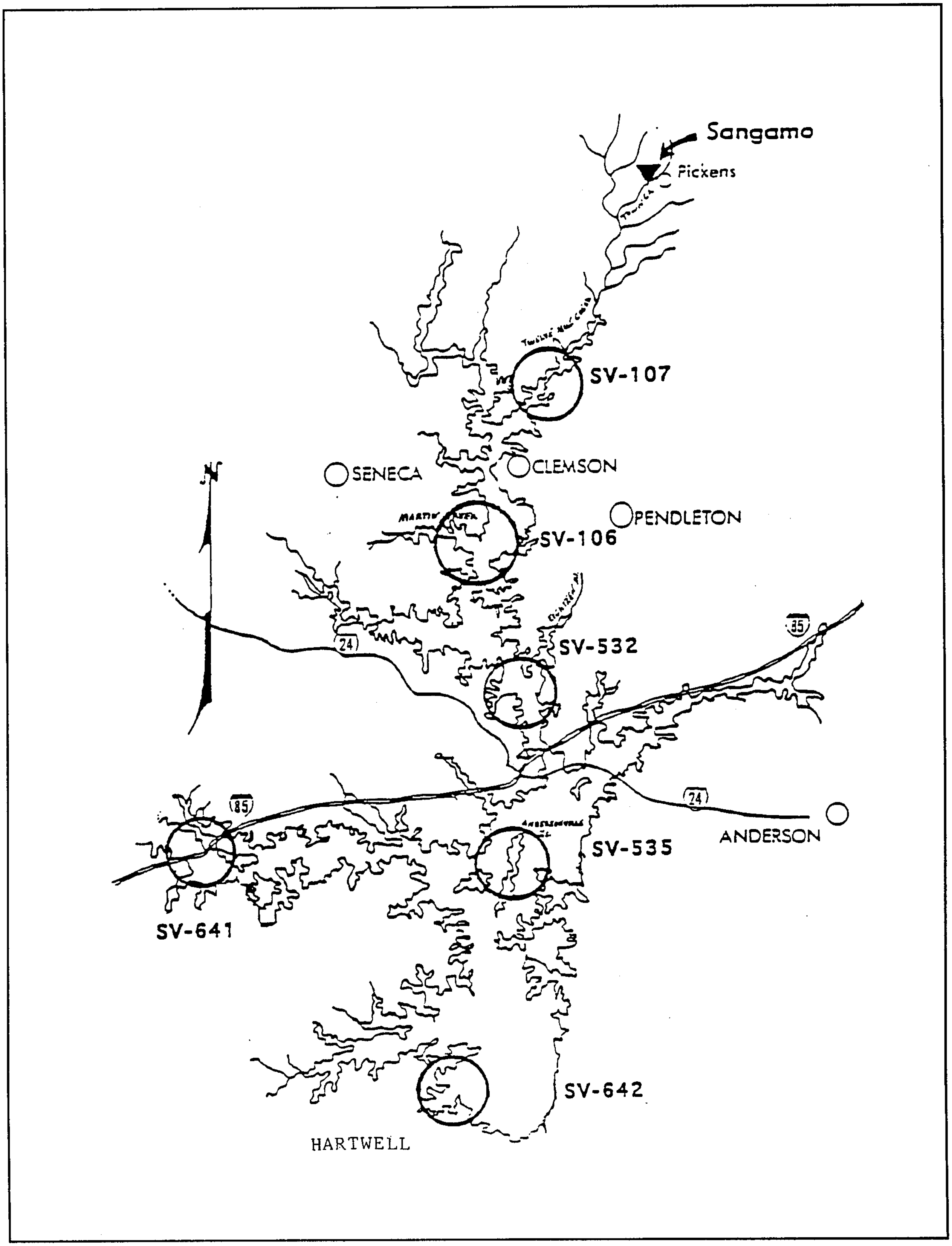


*Figure 2. Lake Hartwell sampling stations*

## Biological Sampling for Contaminant Analysis

Twenty fish were collected for PCB contaminant studies from each of the stations in the Twelve Mile Creek watershed and one tributary reference site. Ten redbreast sunfish and ten northern hog suckers were collected per site. Largemouth bass and bluegill were substituted for redbreast sunfish at three stations.

Sport fish species selected for Lake Hartwell contaminant analysis included largemouth bass, hybrid bass, and channel catfish. Ten largemouth bass, ten hybrid bass, and four channel catfish were collected per station. Totals of 134, 144, and 144 fish were collected from six locations throughout Lake Hartwell during spring 1991, 1992, and 1993, respectively. These fish were analyzed for PCB concentrations in fillets. Additionally, the 60 largemouth bass collected in 1991 were analyzed for priority pollutants.

Forage fish, including bluegill, threadfin shad, gizzard shad, and blueback herring, were collected from SV-107, SV-532, and SV-641. Five whole fish were composited for each forage species sample. Six forage fish samples were collected for each species per station.

Drift net samples were used to collect detritus in Town Creek downstream of the Sangamo site and in Twelve Mile Creek at Lay Bridge. Additionally, cages of "clean" *Corbicula fluminea* were placed at these sites for 28 days to determine rates of bioaccumulation of PCBs by analyzing the muscle tissue.

Clam baskets were also placed in Lake Hartwell at two sites within station SV-107 in the Twelve Mile Creek embayment and at one site at SV-641 in the Tugaloo River arm. Analysis of *Corbicula* from the source in the Hudson River, Madison County, Georgia, was conducted to establish a control. Plankton net samples and mayflies were also collected at SV-107.

## Methods Used for Assessment of the Health of the Aquatic Biota in Twelve Mile Creek and Lake Hartwell

Studies were conducted to assess the health or condition of individuals, populations, and/or communities in the Twelve Mile Creek watershed and Lake Hartwell. The IBI, proposed by Karr (1981), was used to assess the general health of the fish community in the Twelve Mile Creek watershed (Gibson and Alexander 1993). This index is based on a set of metrics determined from species composition and abundance for a fish community. The benthic macroinvertebrate community of Twelve Mile Creek watershed was evaluated using USEPA's rapid bioassessment protocols (Self and Vezertzis 1993).

The HAI was employed to assess the health of redbreast sunfish in Twelve Mile Creek and largemouth bass in Lake Hartwell (Self 1993). HAI is an autopsy-based index that uses divergence from the normal of various organs, tissues, and blood parameters to evaluate fish health. This is not a diagnostic technique but has proven effective in identifying fish health problems related to environmental degradation.

Along with the HAI, lengths, weights, and otoliths were collected for age and growth-distribution determinations for redbreast sunfish in the Twelve Mile Creek samples. Lengths, weights, and scales were collected for age and growth studies of largemouth bass in Lake Hartwell (Foltz and Mattison 1993).

Biomonitoring that used biological indicators of fish health and that assessed the effects of PCB contamination on the reproductive success of key fish species was conducted at both Twelve Mile Creek and Lake Hartwell study sites (Greeley et al. 1993). Biological indicators were used as biomonitoring tools because they can (a) provide early warning signals (predict future trends) of potential

adverse ecological effects, (b) aid in the identification of causal mechanisms underlying observed effects at higher levels of biological organization, (c) assess the integrative effects of contaminant stress on fish, and (d) evaluate the effectiveness of remedial actions on the health of aquatic systems. Many of the selected suite of bioindicators measured in this investigation were employed in a preliminary investigation in Lake Hartwell in Spring 1990. They provided useful information concerning the effects of chronic PCB contamination on fish populations in the reservoir (Adams and Greeley 1991).

## Distribution of PCBs in the Aquatic Biota

PCBs were detected at all levels of the food chain in both the Twelve Mile Creek watershed and Lake Hartwell. During these investigations, a limited number of organisms could be sampled. However, concentrations of PCBs in samples of allochthonous detritus, bioaccumulation by introduced (caged) and native *Corbicula*, benthic macroinvertebrates, seston (USEPA 1993), forage fish species, omnivorous fish species, and piscivorous fish species demonstrated wide distribution of PCBs throughout the food chain (Gaymon 1992a,b,c).

Concentrations of PCBs in fish collected in the Twelve Mile Creek watershed were highest in Town Creek and Twelve Mile Creek. Four of the twelve stations sampled had PCB values exceeding 2.0 ppm (Figure 3). Three of these stations (5, 8, and 12) were downstream from the Sangamo Plant site. Station 4, the other station having high PCB concentrations, was located just upstream from the confluence of Town Creek and Twelve Mile Creek and was probably affected by fish migrating from both creeks. Stations upstream from station 4 could not be affected by migration because of a low head dam located at the upper boundary of station 4. Mean PCB

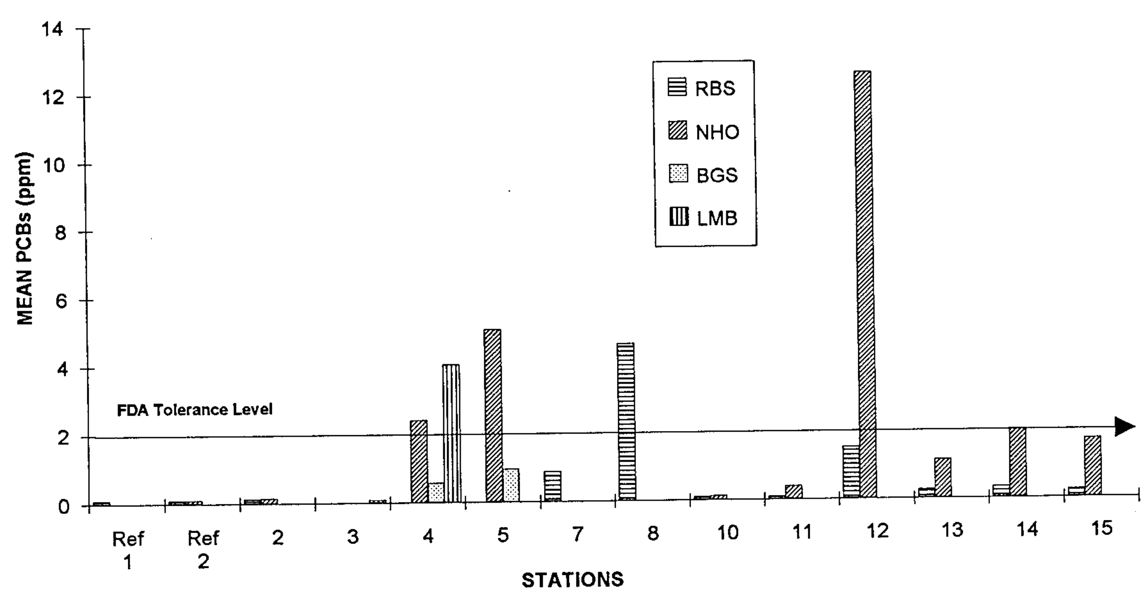


*Figure 3. Mean PCB concentrations in redbreast sunfish (RBS), northern hog sucker (NHO), bluegill (BGS), and largemouth bass (LMB) from 2 reference stations and 12 stations in the Twelve Mile Creek watershed, 1992*

concentrations range from a high of 12.5 ppm for northern hog sucker in Town Creek to a low of 0.88 ppm in redbreast sunfish in Twelve Mile Creek for stations downstream from the Sangamo Plant site (Gaymon 1992c).

The remaining stations located in tributary streams or upstream from the Sangamo Plant site had lower PCB values than those that were down gradient from the plant (Figure 3). Northern hog suckers had higher concentrations than redbreast sunfish at all sites. This would be expected since northern hog suckers were analyzed as whole fish while redbreast sunfish were filleted. Additionally, northern hog sucker appeared to migrate in and out of the area being more heavily contaminated (Twelve Mile Creek) as evidenced by the wide distribution of PCB concentrations in each 10-fish sample.

PCB concentrations in fish have historically been highest in the Twelve Mile Creek arm of Lake Hartwell (SV-107) and decrease in a downstream direction. This is expected since PCBs enter Lake Hartwell bound to sediments washed down Twelve Mile Creek. Once these sediments reach the lentic waters of Lake Hartwell, they settle to the bottom. The distribution of PCBs in the sediments of Lake Hartwell is described in the Remedial Investigation Report for the Sangamo Weston, Inc./ Twelve Mile Creek/Hartwell Lake Site, Operable Unit Two (Bechtel 1993).

Results of PCB analyses for largemouth bass, channel catfish, and hybrid bass were compared for 1990, 1991, 1992, and 1993. These years were comparable since analyses were completed in the same manner. Although 4 years of data may be insufficient to justify meaningful trend analysis, PCB concentrations decreased significantly in largemouth bass at SV-107 (Figure 4). This trend was not significant at other stations. As in past samples, PCB concentrations in largemouth bass decreased in a downstream direction.

PCB concentrations in channel catfish have also decreased at stations farther from

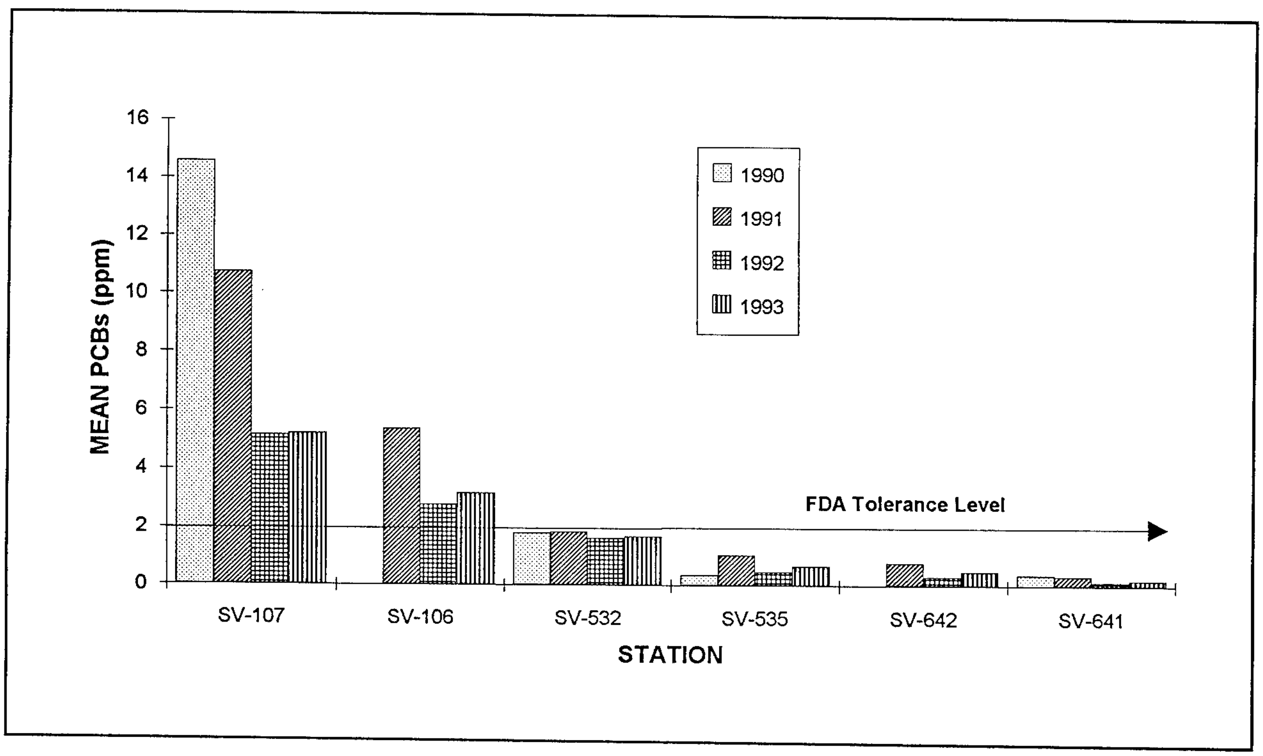


*Figure 4. PCB concentrations in largemouth bass fillets collected from six stations in Lake Hartwell, 1990-1993*

the source in Twelve Mile Creek (Figure 5). However, there has been little change in the PCB concentrations in channel catfish over the past 4 years.

The distribution of PCB concentrations in hybrid bass throughout the lake remains a concern. Hybrid bass collected farther from the source in Twelve Mile Creek have higher PCB concentrations than other species, often exceeding the U.S. Food and Drug Administration (USFDA) tolerance level of 2 ppm (Figure 6). This is thought to be a result of their migratory behavior and is also seen in the samples of walleye, another migratory species having high concentrations of PCBs (mean 3.48 ppm) from SV-642 at Hartwell Dam (Gaymon 1992a,b).

Forage fish species had mean PCB concentrations ranging from 3.00 ppm in threadfin shad to 12.43 ppm in gizzard shad at SV-107 (Gaymon 1992a). PCB concentrations in forage fish decreased at stations farther from Twelve Mile Creek. This supports the hypothesis that migratory species bioaccumulate PCBs while located in the upper Seneca River rather than through the food chain as forage species migrate out of the more heavily contaminated area.

Contaminants other than PCBs were not identified at concentrations of concern, nor were they widely distributed. A comparison of the priority pollutants to the established USFDA action levels showed that no chemical exceeded any of the safe tolerance standards except PCBs. Priority pollutants having no standards were compared with the South Carolina Department of Health and Environmental Control fish tissue trend database. Out of 60 largemouth bass, there were 17 different compounds (mostly petroleum and organic solvents) that occurred only once in a single fish and several others that occurred only twice. There was no pattern of contamination, and PCBs are considered the only contaminant of concern (Gaymon 1992a).

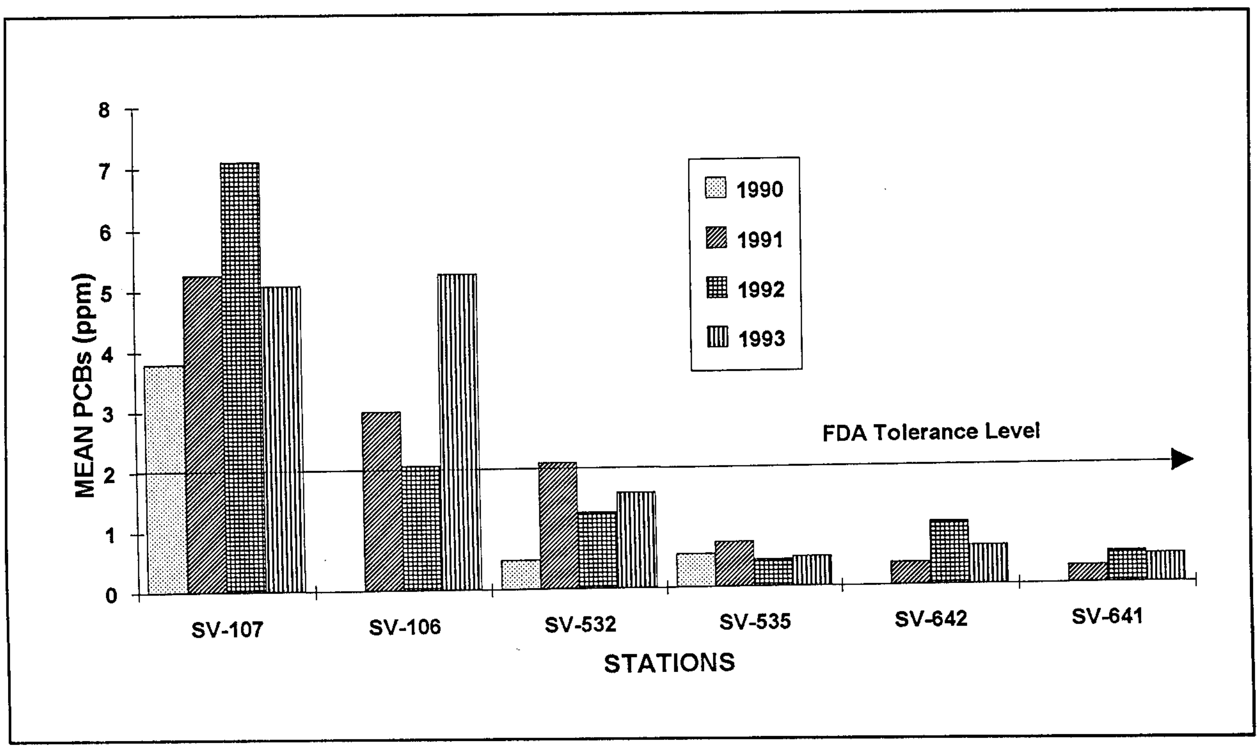


*Figure 5. PCB concentrations in channel catfish fillets collected from six stations in Lake Hartwell, 1990-1993*

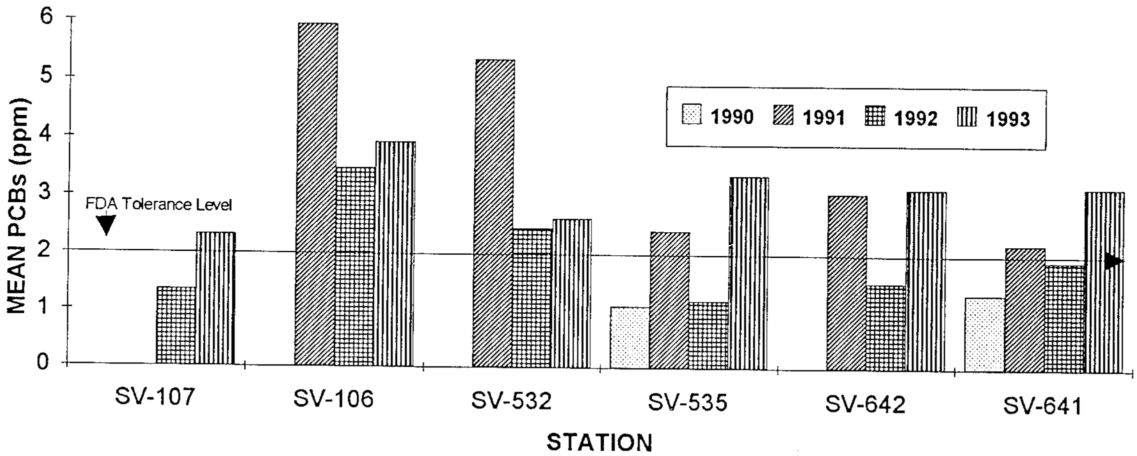


*Figure 6. PCB concentrations in hybrid bass fillets collected from six stations in Lake Hartwell, 1990-1993*

## Assessment of the Health of the Aquatic Biota in Twelve Mile Creek and Lake Hartwell

The benthic macroinvertebrate community of the Twelve Mile Creek watershed was evaluated using USEPA's rapid bioassessment protocols to evaluate habitat impairment. Eight of the nine stations sampled in the Twelve Mile Creek drainage were classified as moderately impaired. Station 11, located upstream of the Sangamo Plant site on Town Creek, was classified as nonimpaired and had high values for taxa richness and exhibited an abundance of intolerant taxa. Sites immediately downstream of the Sangamo facility exhibited evidence of greater impairment than did upstream or tributary sites (Self 1993).

The IBI was used to assess the general health of the fish community in the Twelve Mile Creek watershed. Nine stations in the Twelve Mile Creek watershed and three reference sites were sampled. The IBI was effective for ranking three reference sites as expected based on no identifiable impacts at station 1 (IBI 40), known impacts of agricultural runoff at station 2 (IBI 30), and a known point source discharge at station 3 (IBI 12). Therefore, it appeared appropriate to use the IBI to assess the relative health of fish populations in the Twelve Mile Creek watershed with confidence (Gibson and Alexander 1993).

The IBI indicated that all stations sampled have been impaired to some degree. Most stations throughout the watershed were classified as either "fair" or "good," indicating moderate negative effects on the fish communities that most likely have resulted from habitat degradation from man's activities. Only the two reference stations 2 and 3 that were identified as having known impacts and station 5, located in Twelve Mile Creek downstream from Town Creek, were classified as "poor" or "very poor." The IBI classification at station 5 ("poor") and a comparison of relative health between sample stations and reference stations indicated that station 5 has been

severely impacted. This is mostly likely due to both habitat degradation and water quality impacts.

An HAI was used to evaluate the health of redbreast sunfish at selected stations in the Twelve Mile Creek drainage and a reference site. The HAI scores for redbreast sunfish were variable throughout the watershed ranging from 39.3 to 62.7. Station 12, located in Town Creek immediately downstream from the Sangamo site, had the lowest HAI score, 39.3, indicating healthy fish at this site (Self 1993).

A biological indicator approach was used to examine the effects of environmental contamination on fish health and reproductive competence. Redbreast sunfish were the target fish species used in the Twelve Mile Creek watershed samples. They were compared with samples collected at a reference stream (Milwee Creek) in another drainage.

Differences in bioindicators were seen between fish collected in Twelve Mile Creek and Milwee Creek. Measures of detoxification enzyme activities or levels of various components of the multifunction oxidase system (MFO) have been used to indicate exposure to and possible effects from various xenobiotics including polycyclic aromatic hydrocarbons (PAHs), PCBs, and pesticides (Payne and Penrose 1975). Microsomal protein, used as an indirect measure of the degree of induction of the MFO system, was significantly higher for both sexes in Twelve Mile Creek (Greeley et al. 1993). Microsomal protein was significantly correlated with PCB concentrations in female redbreast.

7-Ethoxyresorufin-O-deethylase (EROD) activities were higher in male redbreast sunfish from Twelve Mile Creek, but not females from the same site. There was no significant correlation between EROD activities and PCB concentrations. EROD values in males at both creeks indicated moderate induction of the MFO system indicating contamination in both streams. The significantly higher microsomal protein levels in both sexes at Twelve Mile Creek and higher EROD activities in males suggest that PCB contamination had some additional role in MFO induction at this site. Differences observed in females were undoubtedly due to the reproductive status of the fish (Greeley et al. 1993).

There were significant differences in some indicators of organ dysfunction at the two creek study sites. Males from Twelve Mile Creek had significantly lower plasma concentrations of creatinine and albumin, while females had significantly lower blood urea nitrogen (BUN) values. In most cases, the relative values of these bioindicators appeared to suggest those fish from the reference site, Milwee Creek, were more environmentally stressed than fish from Twelve Mile Creek (Greeley et al. 1993).

The condition factor (k) that describes length-weight relationships, a measure of nutritional status, was slightly lower for Twelve Mile Creek fish when compared with fish from the reference stream. The liver somatic index, which reflects nutritional status, metabolic energy demands, and is sensitive to toxicant stress because of hypertrophy and hyperplasia, was significantly lower for fish collected from Twelve Mile Creek. The splenic-somatic index, which can indicate infection or disease, did not differ between sites. Additional indicators of feeding and nutrition including serum triglycerides, stomach and intestinal fullness, and gallbladder color clearly indicated a lower nutritional status for redbreast sunfish in Twelve Mile Creek as compared with Milwee Creek (Greeley et al. 1993).

Histopathological screenings of liver tissue samples were nearly identical at the two study sites. This suggests that liver function was not adversely affected in redbreast sunfish from Twelve Mile Creek as compared with the reference site.

Gonadal analyses indicated no significant difference between sites in mean batch fecundity or the female gonadal-somatic index

(GSIs). The male GSIs at Twelve Mile Creek was significantly higher than at Milwee Creek. The redbreast sunfish reproductive competence in Twelve Mile Creek appeared normal with some concern about the quality of the gametes produced (Greeley et al. 1993).

The HAI, biological indicator analyses, and age and growth analysis were used to examine the effects of environmental contamination by PCBs on fish health and reproductive competence in Lake Hartwell. Largemouth bass were the target fish species sampled. Comparisons of fish health using the HAI as the indicator were made among all six stations sampled in Lake Hartwell in 1992 and 1993. Additionally, the HAI was determined for largemouth bass in 1990 (Adams and Greeley 1991) at three stations representing a worst, moderate, and best case area for PCB contamination in Lake Hartwell.

Differences in the HAI were seen between stations. Station SV-107 consistently had the highest HAI score for each year sampled. Station SV-106, the closest downstream station, also had high HAI scores. During 1992, these two stations exceeded 80, while stations farther from Twelve Mile Creek ranged from 42 to 65. Fish from Twelve Mile Creek (SV-107) and Martins Creek (SV-106) had the highest occurrence of fatty liver conditions. Accumulation of fat in the liver can be associated with exposure of fish to PCBs. The remaining stations had a greater percentage of normal livers with little occurrence of fatty livers (Self 1993). Although HAI scores only indicate the relative health of fish without indicating cause, decreases in the HAI scores with distance from the source was consistent with declines in PCB concentrations in fish at these stations.

Measurements of the level of various components of the multifunction oxidase system (production of detoxification enzymes) can indicate exposure and effects from PCBs (Payne and Penrose 1975). Phase 1 detoxification enzymes of the liver are present within the microsomal protein. Therefore, levels of microsomal protein are used as an indirect measure of the degree of increases in detoxification enzymes caused by exposure to environmental contaminants.

Microsomal protein levels were significantly higher in female largemouth bass at SV-106 when compared with the reference site (SV-641). There was not a significant correlation between PCB concentrations and microsomal protein. In male largemouth bass, there was no significant difference in microsomal protein between stations. Microsomal protein was positively correlated with PCB concentrations in muscle tissue of male largemouth bass at all three stations.

Adams and Greeley (1991) reported significantly higher microsomal protein levels for both male and female largemouth bass from SV-107 and SV-532 when compared with the reference at SV-641. However, PCB concentrations did not correlate well with microsomal protein levels.

Activity of EROD is described as among the best general indicators of contaminant exposure for aquatic organisms and is known to be specifically induced by PCBs in fish (Greeley et al. 1993). EROD activities were significantly elevated in male largemouth bass from SV-107 and SV-106 when compared with the reference site (SV-641). No significant difference was determined for female largemouth bass. When PCB concentrations were compared with EROD activities, male largemouth bass had a highly significant positive correlation between PCB burdens and EROD activities. This relationship did not occur in female largemouth bass. EROD activities were significantly higher in both male and female largemouth bass at SV-107 when compared with the reference site (SV-641) during the 1990 investigation (Adams and Greeley 1991).

Plasma or serum levels of serum albumin, creatinine, alanine aminotransferase (ALT), and BUN have been used as indicators of organ dysfunction. There were few statistically significant differences between levels of

these bioindicators when compared between stations. Serum albumin was significantly correlated with PCB concentrations for both male and female largemouth bass. Additionally, BUN was significantly elevated in female bass from SV-106 (Greeley et al. 1993).

Adams and Greeley (1991) reported elevated levels of these bioindicators in fish collected at the more contaminated sites during the 1990 investigation. They found serum albumin to be significantly elevated in male and female largemouth bass at station SV-532. Creatinine levels were higher in female bass from SV-107 and SV-532. ALT levels were significantly elevated in female largemouth bass at both SV-107 and SV-532. BUN was also significantly elevated in male and female largemouth bass at SV-107.

There were few differences among sites in the histopathological condition of the liver or the spleen for either sex. These findings are in general agreement with the findings of the 1990 investigation (Adams and Greeley 1991).

The nutritional status of the organism is important in interpreting the nature of stress responses. Indicators of feeding and nutrition including the percentage of food in the stomach and in the intestine, gallbladder color, and serum triglyceride levels demonstrated no significant trends among stations (Greeley et al. 1993). Although nutritional status was reported as unresolved during the 1990 investigation (Adams and Greeley 1991), most of the indicators appear to be in agreement between the two studies. This suggests that nutrition is similar between stations and would be expected to have little influence on differences in fish health or bioindicators measured during this investigation.

The visceral-somatic index (VSI) and muscle lipid levels were compared between stations as a measure of long-term energy storage. Although there was no significant difference in fat storage or general nutritional status of the fish comparing these indicators, lipid levels in liver tissue proved to be one of the more significant differences between sites. The levels of liver lipids in both male and female largemouth bass were significantly higher at SV-107 and SV-106. Liver lipids were correlated with PCB body burdens. Elevated liver lipids may result from an inability to convert the lipids in hepatocytes to a phospholipid form suitable for use (Greeley et al. 1993). Fatty livers were also identified during the HAI analysis at SV-107 and SV-106.

There was no significant difference in condition indices when comparing the condition factor (k), the liver-somatic index (LSI), or the splenic-somatic index (SSI) between stations. The LSI was negatively correlated with PCB body burden in male largemouth bass compared across all three stations. The SSI was positively correlated with PCB levels in female largemouth bass from Lake Hartwell. These results are in general agreement with the 1990 investigations (Adams and Greeley 1991). Other bioindicators including cell cycle analysis, whole blood analysis, and DNA analysis indicated differences in the physiology of largemouth bass between sites.

Various analyses were conducted to determine the reproductive competence for largemouth bass in Lake Hartwell. Direct effects on the reproductive process were investigated by conducting gonadal analyses including measuring batch fecundity, flow cytometry for evidence of aneuploidy, and histolopathological inspection of testis. These data suggest that PCB contamination of Lake Hartwell is having little effect on the quantity of gametes produced by male or female largemouth bass or on the quality of gametes produced by males. There is some evidence that suggests a trend of greater incidence of damaged oocytes in the more contaminated stations of Lake Hartwell (Greeley et al. 1993).

Improper functioning of the reproductive endocrine system could impact gamete quality or reproductive behavior. Concentrations of several reproductive steroids were measured including estradiol and testosterone. There was no significant difference in plasma levels

of estradiol between female largemouth bass collected at each site. Testosterone was significantly lower in both males and females at SV-107 when compared with SV-641. PCB concentrations were negatively correlated with testosterone levels in both male and female largemouth bass from Lake Hartwell. Additionally, estrogen receptors in liver tissue from both sexes were suppressed at SV-107, while nonspecific binding of estrogen was increased (Greeley et al. 1993).

Age and growth studies were conducted at the six lake stations during Spring 1992 (Foltz and Mattison 1993). Largemouth bass from station SV-107 (Twelve Mile Creek) were significantly different in length-weight than at the other stations. They were less plump having lower weights per unit of length. Mortality rate did not differ between sites. During the 1990 investigations, the growth rate for largemouth bass at SV-107 was similar to other stations up to age 4. After age 4, a significant reduction in growth rate was reported. The mortality rate reported for Twelve Mile Creek was much higher for largemouth bass 3 years and older in 1990 than at the other two stations (Adams and Greeley 1991).

## Conclusions

Fish in the Twelve Mile Creek drainage are contaminated with PCBs, often at levels that exceed the USFDA limit of 2 ppm. PCB levels in fish are higher in areas that are downgradient from the Sangamo facility, indicating a continuing contribution of PCBs from the plant site. This was confirmed with drift net samples and caged clams accumulating detectable levels of PCBs in Town Creek and Twelve Mile Creek in a relatively short period of time.

Both the macroinvertebrate and fish communities have been impaired throughout the Twelve Mile Creek watershed. There is little doubt that these impairments have resulted from habitat degradation, particularly siltation because of erosion from development, silviculture and agriculture, and poor water quality from both point and nonpoint discharges throughout the watershed. It is likely that PCBs have contributed to the impairment of these populations.

It is not evident from evaluating the HAI scores that the health of redbreast sunfish has been affected by PCB contamination. HAI scores were variable throughout the drainage. Additionally, scores in the range seen during this investigation were not considered high. It is likely that health problems that would manifest themselves to visual inspection through autopsy do not occur in fish contaminated at the lower PCB concentrations seen in redbreast sunfish in the Twelve Mile Creek drainage.

Bioindicator and reproductive assessment of the health of redbreast sunfish in Twelve Mile Creek as compared with those in Milwee Creek indicated that the biochemical and physiological responses of fish were segregated between sites. However, many of the bioindicators suggested that the health of the fish from Milwee Creek was being affected by contaminants other than PCBs. Additionally, the bioindicators used to measure condition, feeding, and nutrition suggested that those fish from Twelve Mile Creek were affected by nutrition. These factors tend to show agreement with the interpretation of the HAI that a clear relationship between fish health and PCBs is difficult to establish at the low levels of contamination measured in redbreast sunfish in Twelve Mile Creek.

It appears that environmental perturbation has occurred in many of the streams in the area sampled making it difficult to distinguish cause. Bioindicator analyses indicated that PCB contamination in Twelve Mile Creek probably contributes but is not the sole cause of impacts on fish health. Additionally, the ecological significance of a deviation in the normal physiological response of an individual can vary. Responses affecting mortality rate or reproduction can obviously put populations at risk. Responses of this magnitude

were not identified by bioindicator analyses of redbreast sunfish in Twelve Mile Creek.

Largemouth bass, hybrid bass, and channel catfish in Lake Hartwell continue to have high PCB concentrations. Since these species are collected as target species, it should be clear that other fish species not sampled in Lake Hartwell would be expected to have elevated PCB concentrations similar to these. The distribution of contaminant levels in fish throughout Lake Hartwell remains similar to past studies. PCB concentrations in fish are generally highest in the Twelve Mile Creek arm of Lake Hartwell, with high concentrations being present in migratory species farther away from the source.

Unlike the interpretation concerning fish health in the Twelve Mile Creek watershed, there appears to be a direct relationship between the health of fish in Lake Hartwell and PCB contamination. No other contaminant was identified in Lake Hartwell at concentrations high enough to be a concern or levels that would be expected to result in the differences observed in the HAI or bioindicator analyses. The nutritional status of the fish appeared to be similar between stations, and many of the bioindicator responses varied among sites in close agreement with similar variation in PCB body burdens.

The HAI was consistently highest in the Twelve Mile Creek embayment (SV-107) of Lake Hartwell and generally decreased at stations farther from the source. Although the HAI is not diagnostic, this index clearly indicated a consistent fish health concern in the more heavily contaminated area.

The bioindicator analyses indicated differences in biochemical and physiological responses in fish when comparing PCB contamination in fish at worst case to best case stations. Bioindicators that have been identified as resulting from PCB contamination during other investigations were often identified in fish from SV-107. Besides differences between stations, there appeared to be similarities in some bioindicators when comparing the results from the 1990 sampling (Adams and Greeley 1991) to the current investigation. However, the bioindicator analyses conducted during Spring 1990 would have to be interpreted as indicating a greater degree of impact to fish health in the Twelve Mile Creek embayment when compared with the current investigation.

During 1990, there was evidence of impairment in gill or renal function of both male and female largemouth bass at SV-107. There was evidence of liver damage in female largemouth bass at SV-107 and SV-532. The survival rates of largemouth bass age 3+ and older from SV-107 were significantly lower than the same age fish from other stations, and growth rates of these older age fish were significantly lower at SV-107 than at other sites. The bioindicator and population analyses for the 1990 investigation provided evidence of organ dysfunction and chronic mortality in the largemouth bass population in the Twelve Mile Creek embayment (SV-107).

During the current investigation, there was evidence of biochemical and physiological differences between stations with largemouth bass from SV-107 exhibiting abnormal responses to several bioindicators. The most obvious physiological difference in largemouth bass between stations related to the functions of the liver. Additionally, age and growth analysis indicated a slower growth rate for largemouth bass at SV-107 than at other sites. This difference could not be accounted for when comparing nutritional status between stations. However, there was no significant difference in survival rate between stations during the current investigation.

When comparing the results of similar investigations in 1990 to 1992, it should be understood that PCB concentrations in largemouth bass at SV-107 in 1992 were only on the average about one-fourth as high as in 1990. This was a highly significant decrease in PCB concentrations that should be considered when evaluating the results of the current

investigation. Fish health effects observed in 1992 may represent a best case scenario in a year when PCB accumulation has been low for the year-classes of fish sampled.

This investigation coupled with the 1990 investigation provides evidence that PCB contamination can affect fish physiology and ultimately fish health. However, these investigations also provide evidence that the degree of impairment to fish health may be dependent on PCB concentrations. The PCB concentrations in largemouth bass at SV-107 in 1990 (21.3 ppm) appeared to have population level effects over a small area of the reservoir. However, these effects could not be identified in 1992, as PCB concentrations decreased in the population sampled to an average of 5.4 ppm. This provides evidence that fish health would not be expected to be affected by PCB contamination outside of stations SV-107 and SV-106. Additionally, the effects of PCB contamination on fish populations in Lake Hartwell should decrease as PCB levels available to the aquatic biota decrease.

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# Evaluating Methods for Statistical Analysis of Less than Detection Limit Data Using Simulated Small Samples

*by*
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## Introduction

Chemical analyses of contaminant residues in environmental matrices (water, sediment, or tissue samples) frequently result in concentrations reported by the analytical laboratory as less than some specified detection limit (DL). Such unknown values (termed "censored" data) preclude statistical estimation and comparison by familiar parametric methods without prior manipulation of the censored observations, although nonparametric methods may be used directly in many cases. A number of techniques have been developed for or applied to the analysis of censored data. The simplest of these are to ignore the unknown data or substitute a constant (such as zero, DL, or DL/2) for all data less than DL. More complex techniques involve substitution of values from an assumed probability distribution (e.g., uniform, normal, or lognormal), including the use of linear regression methods; Winsorization or trimmed means; maximum likelihood estimation; and some of the classic survival analysis methods. A number of studies have investigated various methods for estimation of the parameters of fairly large-sample air and water quality data sets, with sample size $n$ ranging from 10 to 135 observations (El-Shaarawi 1989; El-Shaarawi and Esterby 1992; Gaskin, Dafoe, and Brooksbank 1990; Gilliom and Helsel 1986; Haas and Scheff 1990; Helsel and Cohn 1988; Helsel and Gilliom 1986; Kushner 1976; Newman et al. 1989; Porter and Ward 1991). However, little work has been done regarding the performance of the various techniques with small sample size typical of dredged material contaminant testing. Gleit (1985) examined several methods for parameter estimation using simulated censored data sets with $n$ as low as 5.

Dredged material contaminant evaluation procedures, described in the Ocean Disposal Testing Manual (the "Green Book," U.S. Environmental Protection Agency/U.S. Army Corps of Engineers (USEPA/USACE 1991)) and draft Inland Testing Manual (USEPA/USACE 1994), typically rely not on parameter estimation but on statistical comparisons between dredged and reference sediments. The comparisons may involve sediment contaminant concentrations or bioaccumulation potential projected from those concentrations or the results of bioassays and bioaccumulation tests. The high cost of chemical analyses for a suite of trace contaminants usually dictates that only a few replicates can be analyzed for sediment or bioaccumulation comparisons ($n = 5$ is typical). The ramifications of less than DL data in small-sample sediment and bioaccumulation testing have been discussed by Clarke (1992) and Clarke and Brandon (in preparation).

This paper describes the methods of a simulation study to compare a number of censored data techniques in various situations involving small sample size. Methods for verification of the simulation results using actual trace chemical data are also described. Although the simulations and verifications have been completed, reduction and interpretation of the output remain to be accomplished, and so study results cannot be presented herein.

The focus of this study is primarily on the outcome of statistical hypothesis testing

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procedures for the comparison of dredged and reference sediment contaminant concentrations or bioaccumulation, as recommended in the draft Inland Testing Manual (USEPA/USACE 1994, Appendix D). The censored data methods that have been shown in previous studies to work well for parameter estimation should not be assumed to perform equally well for statistical comparisons since the objectives of estimation and comparison are different. The objective of statistical estimation is to approximate true population parameters as closely as possible using sample data. Statistical comparisons, on the other hand, imply little or no interest in the true value of population parameters, but only in whether populations differ from each other in some respect (usually in location, or mean value). Ideally, manipulation of censored data for statistical comparisons should result in comparisons that retain the power (ability to detect true significant differences among populations) and confidence (avoiding detection of significant differences when in reality there are none) of tests using similar, uncensored data. Acceptable methods for handling censored data should be usable even with a high percentage of censoring.

## Monte Carlo Simulations

Evaluation of censored data techniques for statistical comparisons necessitates knowledge of the true outcome of the statistical comparisons, which in turn implies knowledge of the true distributional parameters (such as mean and variance) of the population of contaminant concentrations under investigation. Because of the fiscal and logistical impossibility of sampling entire populations of sediment contaminant concentrations to determine the true values of their distributional parameters, simulation of populations using computer-intensive Monte Carlo techniques becomes an attractive alternative. Simulation creates artificial populations of values whose characteristics are known with certainty and are expected to resemble those of natural distributions of contaminant concentrations. The basic steps in the simulation procedure for this study were described by Clarke and Brandon (in preparation).

### Parameter Specifications

A total of 670 groups of populations were generated using random numbers and specified distributional parameters. Normal, lognormal, and gamma probability distributions were used to generate the populations. These distributions are all possible for contaminant concentrations in the environment, although the lognormal is perhaps most likely and is sometimes assumed in analyses of environmental trace chemical data (El-Shaarawi 1989; Gilliom, Hirsch, and Gilroy 1984; Kushner 1976; Newman et al. 1989; Ott and Mage 1976; Porter and Ward 1991; Travis and Land 1990). The distributions were chosen to correspond to the types of statistical comparison procedures recommended in USEPA/USACE (1994): parametric tests using untransformed data, parametric tests using log-transformed data, and nonparametric tests, respectively. For each group, one population was generated to represent the reference sediment, and one to three additional populations were created to represent the dredged sediment(s) that would be compared with the reference. The mean of each reference population was set to 1. Reference population standard deviations were set to 0.1, 0.5, 1, 2, or a random number between 0.1 and 2. This range encompassed nearly the entire range of coefficients of variation calculated for 530 samples of uncensored sediment or tissue contaminant concentration data from several projects involving sediment contaminant evaluations.

Means for the simulated dredged sediment contaminant populations were set equal to 1 for some comparisons to test for Type I statistical error (false positives, i.e., finding significant differences when in reality there are none). For other comparisons, dredged sediment means were set to some value greater than 1 to test for power. Because statistical power ranges from 0 to 1, the maximum dredged sediment means for these comparisons were chosen based on an approximate

power of 0.5 for uncensored data comparisons, so that differences in power among the censored data techniques could be most easily distinguished. Standard deviations for the simulated dredged sediment populations were set so that they would be (a) equal to the reference sediment standard deviation, (b) proportional to the means, or (c) some mixture of values between 0.1 and 2. These alternatives correspond, respectively, to the statistical comparison situations in which (a) variances among treatments are equal, (b) variances increase with increasing means, or (c) variances among treatments are not equal and follow no particular pattern with respect to the means.

Once a group of populations was generated for a given sediment comparison, 500 random samples were drawn from each population. Each sample consisted of several replicates. Sample sizes were equal with 5 or 8 replicates for each sediment or unequal with the reference sediment having either the most replicates ($n = 6$, dredged sediment $n = 5$, 4, or 3) or the fewest replicates ($n = 3$ or 4, dredged sediment $n = 6$). Percentiles were calculated for the entire reference sediment population. Detection limits corresponding to given percentiles of that population were imposed so that 20, 40, 60, 80, or 95 percent of the reference sediment population fell below DL. The same DLs were then applied to the dredged sediment population(s), but different percentages of those populations would be affected depending on their means and standard deviations. Although reference population censoring percentiles were predetermined, each sample had a variable number of censored observations ranging from 0 to $n$. This corresponds with the type of censoring that occurs in chemical analytical practice, where the detection limit is known but the number of observations falling below DL varies from sample to sample.

Parameter specifications are summarized in Table 1. All simulations, including population generation and subsequent analyses, were conducted using SAS (SAS Institute, Inc. 1988a,b) under the UNIX operating system.

## Censored Data Methods

Following selection of the 500 samples from each population, 10 different censored data methods were applied to each sample.

**Table 1**
**Parameter Specifications for Monte Carlo Simulations**

| Parameter | Specifications |
|---|---|
| Population distributions | normal, lognormal, gamma |
| Number of dredged sediments to be compared with a reference | 1, 2, 3 |
| Reference sediment mean | 1 |
| Dredged sediment means | 1, 1.06, 1.12, 1.6, 2.2, 4.4 |
| Standard deviations | equal, at 0.1, 0.5, 1, 2 proportional to means mixed, between 0.1 and 2 |
| Number of samples per population | 500 |
| Sample sizes | equal, $n = 5$<br>equal, $n = 8$<br>unequal, $n = 6$ (reference), 5,4,3 (dredged)<br>unequal, $n = 3,4$ (reference), 6 (dredged) |
| Censoring percentiles | 20, 40, 60, 80, 95 |
| Total number of simulations | 335,000 |

All methods involved assignment of a numeric value to each censored observation; the methods differed in what values were assigned and how those values were determined. The ten methods were as follows:

*a.* Substitution of zero.

*b.* Substitution of DL.

*c.* Substitution of DL/2.

*d.* Substitution of evenly spaced numbers between 0 and DL (UN method in Gilliom and Helsel 1986).

*e.* Substitution of random numbers from a uniform distribution between 0 and DL.

*f.* Substitution of estimated values from a normal distribution using linear regression of above DL concentrations versus their rankits (NR method in Gilliom and Helsel (1986)).

*g.* Substitution of estimated values from a lognormal distribution using linear regression of logarithms of above DL concentrations versus their rankits (LR method in Gilliom and Helsel (1986), LPP method in Helsel (1990) and Clarke (1992)).

*h.* Maximum likelihood estimation of below DL values assuming a normal distribution for censoring (SAS Institute, Inc. 1988a).

*i.* Maximum likelihood estimation of below DL values assuming a lognormal distribution for censoring (SAS Institute, Inc. 1988a).

*j.* Maximum likelihood estimation of below DL values assuming a Weibull[1] distribution for censoring (SAS Institute, Inc. 1988a).

Several other methods mentioned in the Introduction were not included in the simulations for various reasons. Winsorization and trimmed means are impossible when censoring exceeds 50 percent and result in excessive information loss at the lower censoring percentiles. Deletion of censored data also results in progressive loss of information as censoring increases, until there is no sample left when censoring reaches 100 percent. The maximum likelihood methods were performed using a survival analysis procedure (LIFEREG) in SAS. Several other survival analysis techniques are available in SAS, including the Kaplan-Meier method (SAS Institute, Inc. 1988c) and the Cox proportional hazards model (SAS Institute, Inc. 1991); however, these procedures could not be adapted for the streamlined output of results required for interpretation of thousands of simulations.

## Statistical Comparisons

The basic statistical comparison tests recommended in USEPA/USACE (1994, Appendix D) were applied to each set of samples at each censoring percentile for each method, as well as to the uncensored data. These tests included Fisher's Least Significant Difference (LSD) test using untransformed data, the LSD test using log-transformed data, and a nonparametric LSD test using data converted to rankits. Number of erroneous outcomes were counted and used to determine power and (probability of Type I error) for each method relative to no censoring.

## Estimation

Although estimation was not the primary focus of this study, the simulations produced information that could be used to evaluate the performance of the censored data methods for estimation. Mean and standard deviation were computed for each sample at each censoring percentile using each method and compared with the known population mean and standard deviation by calculation of their respective root mean square errors (rmse) (Gilliom and Helsel 1986). Methods having

[1] The Weibull is related to the gamma distribution.

the lowest rmse would be considered best for estimation of population parameters. Rmse were also calculated for the uncensored data.

## Verifications

Following completion of the simulations, the 10 censored data methods were investigated in a verification study using actual chemical concentration data from sediment and tissue samples analyzed for several dredged material contaminant evaluation projects. The data comprised 1,079 samples for a total of 271 comparisons. One to five dredging project samples were simultaneously compared with a reference sample. Most sample sizes ranged from 3 to 6 replicates, although a few comparisons included samples of 1, 2, 7, 10, 11, or 12 replicates. Comparisons involved both equal and unequal sample sizes. The data were censored at the 20, 40, 60, 80, and 95th percentiles of the overall distribution for each set of samples. Parameter estimation and statistical comparisons were then performed as described above. The verification study was conducted using PC/SAS (SAS Institute, Inc. 1988a,b).

## Conclusions

The simulation study (a total of 335,000 simulations) and the verification study have been completed. However, interpretation of the massive output from these studies is still pending. Results will be interpreted for the various coefficients of variation, censoring percentiles, data transformations, etc., used in the studies, and a comprehensive evaluation will be prepared as well. Preliminary interpretation of results suggests that data-censoring methods previously recommended for parameter estimation using large-sample data sets (generally, the maximum likelihood and linear regression techniques) may not perform well for statistical comparisons of small-sample data sets, and that no methods work well when censoring is extreme (80 to 95 percent). Guidelines for statistical treatment of less than DL data in dredged sediment evaluations will be proposed following complete interpretation of the study results. Guidelines will apply primarily to analyses in which observations of a given sample are censored at a single DL; the simulation study was not designed to address multiple detection limits.

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